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DEPARTMENT OF DEFENSE

ELECTROMAGNETIC COMPATIBILITY ANALYSIS CENTER

COMPATIBILITY FACTORS AFFECTING CONCEPT DEVELOPMENT OF APPROACH AND LANDING GUIDANCE SYSTEM

Prepared by M. Maiuzzo
of the IIT Research Institute

May 1970

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Technical Report

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FOREWORD

The Electromagnetic Compatibility Analysis Center (ECAC) is a Department of Defense facility, established to provide advice and assistance on electromagnetic compatibility matters to the Secretary of Defense, the Joint Chiefs of Staff, the military departments and other DOD components. The Center, located at North Severn, Annapolis, Maryland 21402, is under executive control of the Director of Defense Research and Engineering and the Chairman, Joint Chiefs of Staff or their designees who jointly provide policy guidance, assign projects, and establish project priorities. ECAC functions under the direction of the Secretary of the Air Force and the management and technical direction of the Center are provided by military and civil service personnel. The technical operations function is provided through an Air Force sponsored contract with the IIT Research Institute (IITRI).

This report was prepared as part of AF Project 649E under Contract F-19628-69-C-0073 by the staff of the IIT Research Institute at the Department of Defense Electromagnetic Compatibility Analysis Center.

To the extent possible, all abbreviations and symbols used in this report are taken from American Standard Y10.19 (1967) "Units Used in Electrical Science and Electrical Engineering" issued by the United States of America Standards Institute.

Users of this report are invited to submit comments which would be useful in revising or adding to this material to the Director, ECAC, North Severn, Annapolis, Maryland 21402, Attention ACV.

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ABSTRACT

Results presented in this report issue from four tasks undertaken for the FAA. These results contribute to the specification of a concept for a guidance system for approach and landing. The electromagnetic emitter environment is established for the 1975 time frame for the frequency bands, 5.0 to 5.25 GHz, 9.0 to 9.2 GHz, and 15.4 to 15.7 GHz. Possible interactions between a proposed guidance system located at John F. Kennedy International Airport and the 9.0 to 9.2 GHz band emitter/receiver environment are established. Estimates are made of the minimum number of separate channels required of a guidance system. Channel frequency separation requirements for a specific signal format/system deployment are also established.

KEYWORDS

C-BAND
X-BAND
Ku-BAND
AIRBORNE
NAVIGATION
ENVIRONMENT
TRANSPONDERS
AIRCRAFT LANDINGS
ELECTROMAGNETIC COMPATIBILITY

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SECTION 1

INTRODUCTION

BACKGROUND

This report summarizes work done by the Electromagnetic Compatibility Analysis Center (ECAC) for the Federal Aviation Administration in response to Task Assignment No. 4 to Inter-Agency Agreement DOT FA70WAI-175. The results were used to provide information to the Special Committee 117 (SC-117) of the Radio Technical Commission for Aeronautics (RTCA).

The Work of SC-117

The basic objective of SC-117 is the development of a concept for an approach and landing guidance system (ALGS) and an associated signal structure. Selection of frequency ranges and an estimation of ALGS channel capacity requirements are factors in meeting the objectives.

The proposed frequency ranges of the ALGS were identified as 5.0 to 5.25, 9.0 to 9.2, and 15.4 to 15.7 GHz at the-time Task Assignment No. 4 was undertaken.

Pertinent Committee Documents

Documents in the form of technical requirements, proposed system concepts, and technical analyses were generated by the committee and its members. Four of these documents, listed below, are especially pertinent to the ECAC effort.

- *Tentative Operational Requirements for a New Guidance System for Approach and Landing* (see Reference 1).

- *Systems Concept Description for Integrated Terminal Guidance* (see Reference 2). The ITG systems concept includes an example of X-band (9.0 to 9.2 GHz) equipment configurations.

- At a later date IIT Gilfillan prepared some notes giving amplification and modifications to the ITG systems concept. (See Reference 3.)

- Several "straw men" formats were proposed, one a pulsed format, is the Paul Bunyan format. A member of the committee prepared some technical notes concerning, among other topics, the channel bandwidths and spacing used in the Paul Bunyan format. (See Reference 4.)

OBJECTIVE OF TASK ASSIGNMENT NUMBER 4

The work that ECAC carried out in response to Task No. 4 is on the electromagnetic compatibility aspects of the ALGS. The tasks undertaken in this context were as follows:

1. Collect frequency allocation and usage data for the frequency ranges designated. Data on pertinent characteristics of the systems in the bands was also to be collected. This information is to be used to aid in selecting a frequency range and design for the ALGS, and provide input data for the achievement of Task No. 2.
2. Determine the channel availability for the proposed ITG system at the John F. Kennedy Airport in New York in the present electromagnetic environment. The ITG system was chosen as a test system to estimate the constraints introduced by the present electromagnetic congestion in the 9.0 to 9.2 GHz range on this type of system. JFK Airport was selected as a typical high-congestion area.
3. Estimate the number of channels required for the ALGS based on its operational requirements (see Reference 1) and future air terminal complexes for U.S. and European areas. The approach and therefore the results were not intended to consider possible interactions between the ALGS and other environmental systems, but considered only possible interactions between ALGS installations.
4. The results of task number 3 represent the number of distinct channels required. The frequency spacing between each distinct channel is a function of system parameters such as modulation schemes and physical location. The objective of task number 4 was to determine channel separation requirements for one of the proposed signal formats, that is, the Paul Bunyan, pulsed format.

APPROACH

In order to identify the primary* electromagnetic emitters, a search was made of the following sources:

- ECAC environmental file, Federal Communications Commission File, and U.S. military radio frequency authorizations. These sources were used to select the current U.S. military and civilian constituents associated with fixed locations.

- ECAC nominal characteristics file and vehicular equipment complement index. These sources were used to select U.S. military and civilian emitters.

* A primary emitter is an emitter authorized operation in the band on a primary basis. A secondary emitter may not cause interference to or claim protection from equipments operating on a primary basis.

- *Frequency allocation assignment records.* These records were used to select future military emitters. (Joint Frequency Panel/J12)

- *ITU and members of SC-117.* These sources were used to select current and future international use of the spectrum.

In order to estimate the channels available to the ITG system, the ITT proposal was examined (see Reference 2), and systems characteristics and operating parameters identified. Simulation of deployment of this system at JFK Airport serving a single runway was performed. The electromagnetic environment was as determined from the usage data. Possible interactions between this single ITG system and its environment were calculated for each of the ITG system's channels. (The ITG concept proposed a capacity of 40 channels.) The number of channels available to this system at JFK Airport was determined based upon the assumption of both a threshold of 0 dB interference-to-noise ratio (INR) and 10 dB INR at the receiver.

In order to estimate the minimum number of distinct channels required for ALGS, projected future air terminal complexes were established for U.S. and European areas. The U.S. air terminal complex was specified for an area with a high density of runways. The area consisted of four states – California, Arizona, Nevada, and Utah. Runways in this area were selected for ALGS service. Similarly, a projected ALGS implementation covering eight countries in Western Europe was also specified. Employing a graph-theoretic approach (i.e. node-coloring algorithms), the minimum number of distinct channels required to support the entire airport/runway complex was determined. This determination was done under a variety of angular coverages, operational alternatives, and cochannel assignment constraints.

In the determination of the channel separation requirements, implied by the Paul Bunyan signal format, a worst case deployment situation was considered. This deployment placed an undesired ALGS transmitter in an approach pattern of an adjacent runway near the system coverage boundary. From this deployment and the system coverage requirements, the minimum channel separation requirements were determined.

SECTION 2

SUMMARY OF RESULTS

SUMMARY OF RESULTS OF ENVIRONMENT STUDY

1. The most significant primary emitters in the ranges 5.0 to 5.25 GHz and 15.4 to 15.7 GHz are airborne. Two exceptions are naval air landing guidance systems, one deployed at naval air stations, in the 5.0 to 5.25 GHz range, and one deployed on aircraft carriers, in the 15.4 to 15.7 GHz range. All primary emitters in the range 9.0 to 9.2 GHz are ground based at airfields (mostly military facilities).

2. The emitters in the 5.0 to 5.25 GHz range operate at specific nominal center frequencies with varying degrees of instability. Two of these emitters are fixed frequency by design limitations. The third, a station keeping system has a specified factory preset frequency of 5090 MHz, however the equipment is designed to enable operation at any frequency in the 5.0 to 5.25 GHz range. It is estimated that all three will operate within less than 130 MHz of this range if present practices are followed.

3. Of the three considered, the 9.0 to 9.2 GHz band is the least desirable from an EMC standpoint. The GCA systems and the ALGS may be required to operate simultaneously at various air terminals. Among the next generation GCA equipment is the AN/TPN-19 PAR. No unused frequency channels will be available within line-of-sight of the AN/TPN-19. This is due to the utilization of the entire band for the chirped pulse emission of that system. The effect of interference from the AN/TPN-19 on the ALGS has not been determined.

4. There are three types of primary systems operating in the 15.4 to 15.7 GHz band. They are: a navigation and weather radar system, used primarily on non-commercial and military aircraft, an aircraft carrier landing system, and a tactical landing system found primarily in non-CONUS areas. The most significant CONUS emitter is the navigation and weather radar. This equipment can potentially operate over a 200 MHz range. Based on current practice that is followed by the equipment installation and maintenance activities, the equipments are tuned to frequencies between 15.450 and 15.500 GHz. Considering their nominal tuned frequencies, 3 dB bandwidths and frequency instabilities it is estimated that this system currently operates in a 90 MHz band.

SUMMARY OF RESULTS OF STUDY OF ITG (9.0 TO 9.25 GHz) SYSTEM IN JFK ENVIRONMENT

1. At the JFK Air Terminal only 10 channels of the 40 channel capacity of the ITG^2 system would be available if the criteria for interference threshold is maintained at an

INR of 0 dB. Relaxing the threshold to 10 dB INR would permit use of two more channels. The proposed modifications to the original ITG system concept are not expected to improve compatibility with the 1970 environment based upon cursory consideration of the effects of modification.

2. It should be noted that the ITG system as proposed conflicts with a current FCC requirement. This requirement does not permit the operation of airborne interrogators in the 9.0 to 9.2 GHz band.

SUMMARY OF RESULTS OF ALGS CHANNEL REQUIREMENTS ANALYSIS

1. Estimates of ALGS channel requirements range from 75 to 157 channels for the four state area in the Southwest U.S. (see TABLE 5-1).

2. Estimates of ALGS channel requirements range from 33 to 126 for the Western Europe air terminal complex (see TABLE 5-2).

SUMMARY OF RESULTS OF STUDY OF ADJACENT CHANNEL IMPLICATIONS OF PAUL BUNYAN FORMAT

The Paul Bunyan signal format configuration proposed in Reference 4 was examined with respect to geographically near, adjacent-channel, facilities. It was determined that a separation of two or three channels will be required for the case where the airborne unit was much closer to the undesired than to the desired facility (see Figure 6-2) and where free space propagation conditions prevailed.

SECTION 3

RESULTS OF ENVIRONMENT STUDY

GENERAL

Data concerning frequency allocation and usage are presented in this section.

U. S. MILITARY SERVICES AND CIVILIAN USERS

The information presented includes:

1. Location or proposed locations of emitters
2. Pulse width
3. 3 dB emission bandwidths
4. Tuning capability, either fixed frequency or tunable
5. Graphs of "received power" versus separation distance
6. Antenna descriptions
7. Pulse repetition frequencies
8. Frequency stability

5.0 – 5.25 GHz Band

The 5.0 – 5.25 GHz environment is presently devoid of primary emitters. The post 1975 time frame will have three primary systems in this band.*These systems are: The AN/UPN-33 navigation system consisting of the AN/TPN-21 (ground portion) and the AN/APN-197 (airborne portion), an airborne station keeping equipment having two types of emissions (i.e., narrow pulse and wide pulse) and the HG 1001 helicopter proximity warning device.

The collection of data for the 5.0 to 5.25 GHz environment lends itself to presentation in the form of tables and figures. See TABLES 3-1 and 3-2 and Figures 3-1 and 3-2.

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*A classified system having a low likelihood of deployment is not included in this report. A developmental frequency authorization is on file at ECAC.

TABLE 3-1 lists the emitters, likely environment, pulsewidth, 3 dB emission bandwidth, whether fixed frequency (F) or range tuned (R), operating frequency, frequency stability, and radiation directivity of emitters in the 5.0 to 5.25 GHz band.

Figure 3-1 shows peak (pulse) power "available" to a victim as a function of separation from each emitter assuming an isotropic receiving antenna.

TABLE 3-2 shows power levels extracted from Figure 3-1 and then converted to power which would be received by an on-tuned 5 MHz bandwidth receiver. This conversion is needed in order to relate power levels to a suggested Paul Bunyan signal format DME bandwidth.

Figure 3-2, (a) and (b), is a graph of the PRF's generated by the specified operating systems. The PRF's are shown as a function of the number of aircraft using that system. The maximum number of aircraft expected to use each system in a single environment is the highest number for which the curves are plotted.

9.0 – 9.2 GHz Band

All primary emitter types expected to be operating in the post 1975 time frame are presently deployed except one, the AN/TPN-19 PAR. The AN/TPN-19 PAR has unique technical characteristics which set it apart from the rest of the emitters. Therefore it is treated separately at the end of this sub-section.

As with the 5.0 to 5.25 GHz band, the data collected on the 9.0 to 9.2 GHz environment is described in a series of tables and figures. The present known environment of primary emitters is set forth in the general descriptions given in the following paragraphs.

There are 62 primary emitters operating in this frequency range. In order to simplify the data presentation, TABLE 3-3 lists these emitters in groups. Each group is composed of emitters having the same pulsewidth, peak transmitted power, and average pulse repetition frequency (PRF). Antenna gains in all groups lie in the range 40 ± 3 dB. The appearance of the same nomenclature in more than one group indicates multi-mode transmissions.

Figure 3-3 shows curves of peak power at an isotropic receiving antenna for each emitter group. For the usual interference case, i.e., nonmainbeam illumination, the received power will be reduced by an estimated 40 dB from the values shown on the curve.

TABLE 3-1
EMITTER DATA, 5.0 TO 5.25 GHz BAND

Emitter	Where Found	Pulsewidth (μ s)	Emission 3 dB Bandwidth (MHz)	Tuning (F/R)	Operating Frequency (MHz)	Stability (MHz)	Antenna Directivity
AN/TPN-21	At Naval Lending Facilities (Ground)	0.1	7.2	F	5170	± 20	Non-Directional
AN/APN-197	Near Naval Lending Fecilities (Airborne)	0.1	7.2	F	5110	± 20	Non-Directional
Station Keeping Equipment No. 1	Along Air Routes (Airborne)	0.1875	5.3	F	5090	± 3	Non-Directionel
Stetion Keeping Equipment No. 2	Along Air Routes (Airborne)	1.0	1.0	F	5090	± 3	Non-Directional
HG 1001	Airborne (See Note)	0.065	20.0	F	5080	± 20	Non Directional

NOTE:

This is a proximity warning device for helicopter training limited in operation to within 35 miles of three locations, Ft. Rucker, Alabame, Ft. Stewart, Georgia, and Camp Wolters, Texas.

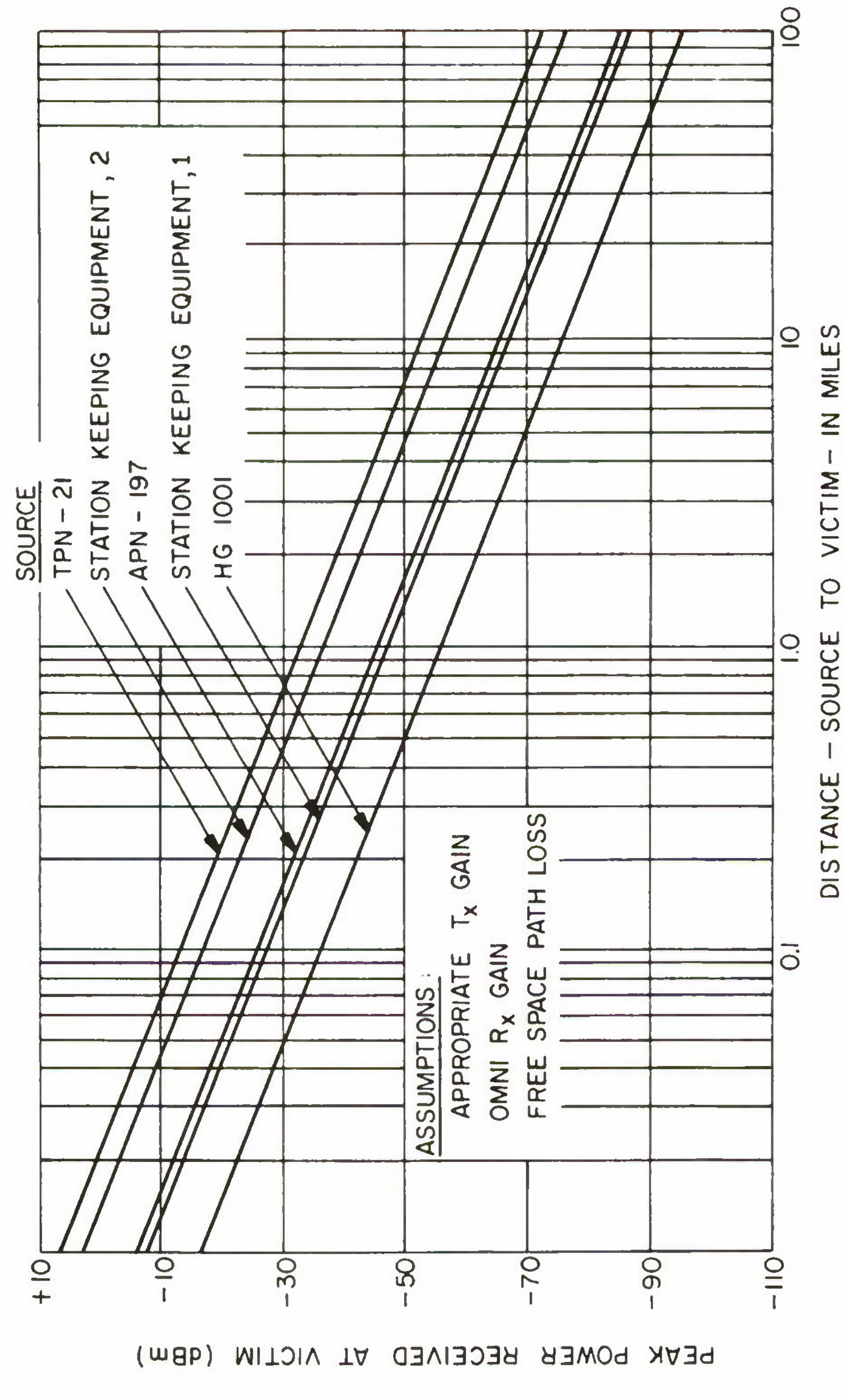

Figure 3-1. Received Peak Power at an Isotropic Antenna as a Function of Distances from Designated Transmitters

TABLE 3-2
POWER AT INPUT TERMINALS OF RECEIVER

Nomenclature	40 Mile Slant Range		1 Mile Slant Range	
	Received Power (dBm)	Power in 5 MHz Bandwidth (dBm)	Received Power (dBm)	Power In 5 MHz Bandwidth (dBm)
AN/TPN-21	−65	−67	−32	−34
AN/APN-197	−78	−80	−46	−48
Station Keeping Equipment No.1	−79	−79	−47	−47
Station Keeping Equipment No.2	−69	−69	−37	−37
HG 1001	−88	−94	−56	−63

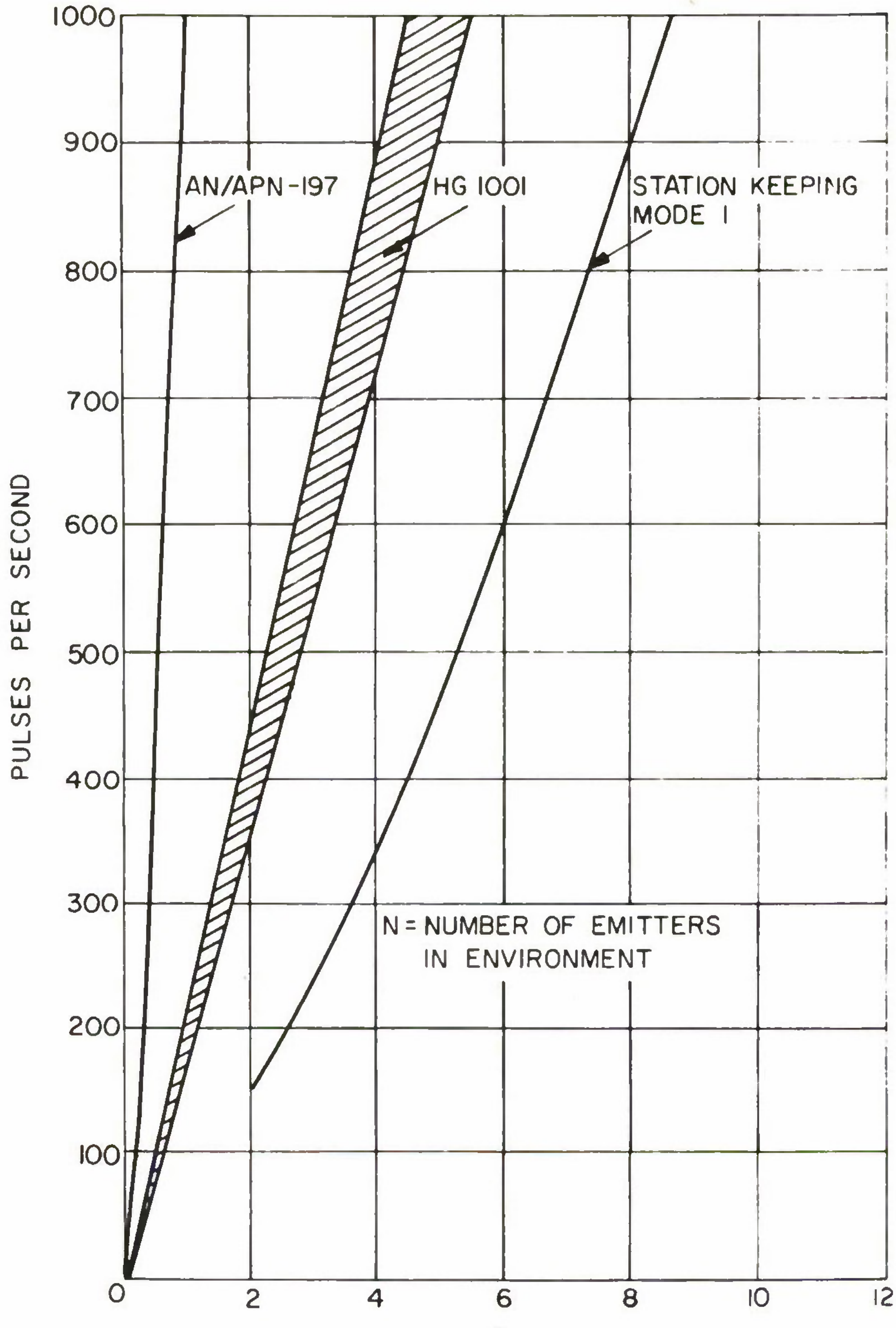

Figure 3-2a. PRF's of 5.0 – 5.25 GHz Emitter Environments

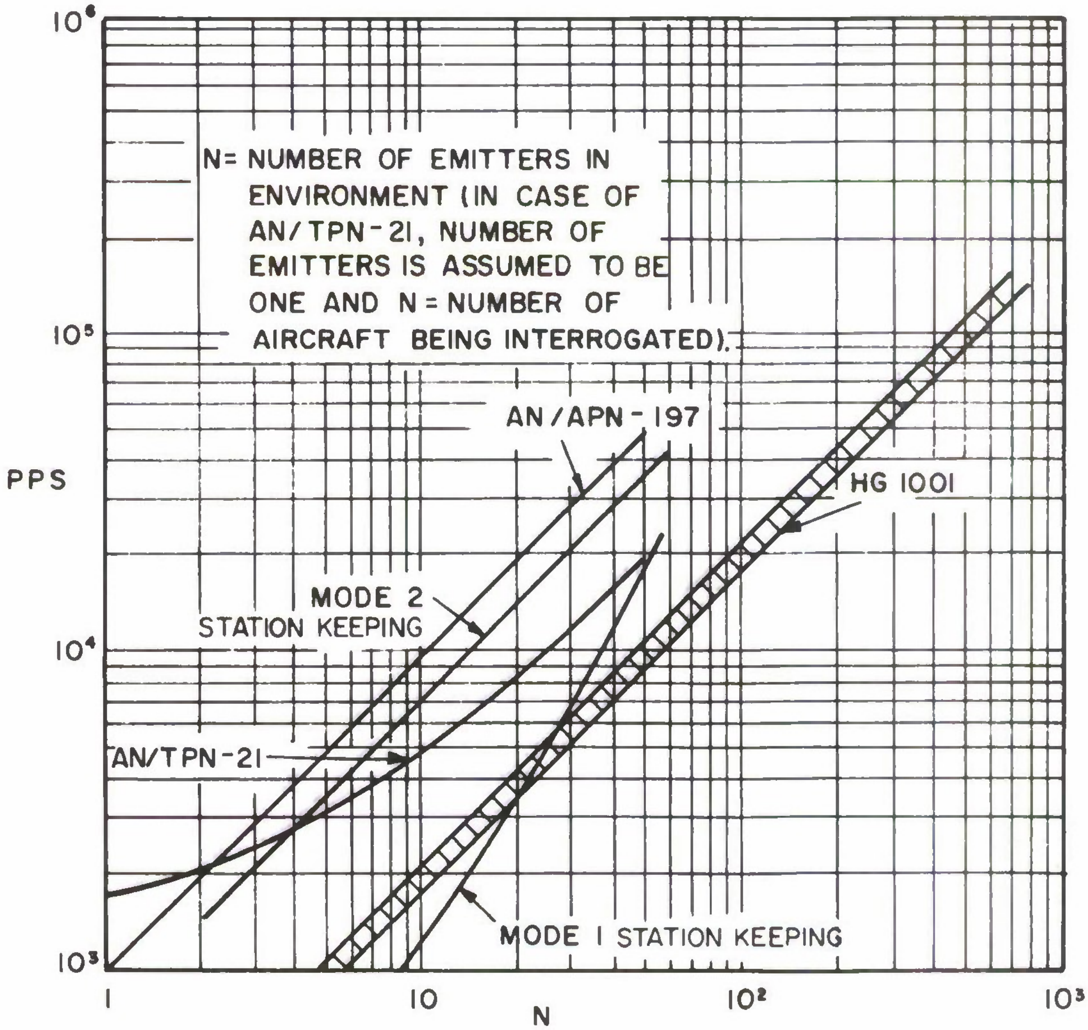

Figure 3-2b. Continuation of PRF's of 5.0 – 5.25 GHz Emitter Environments

In order to present the environment as a function of pulse characteristics the 24 main groups were further consolidated into four categories according to pulsewidths. TABLE 3-4 lists the four categories, the groups that fall under each category and summarizes the waveform emission characteristics.

Figures 3-4 through 3-7 and TABLE 3-5 contain information concerning primary emitters located within 200 miles of JFK airport. Similar information concerning emitters around nine other airports is given in APPENDIX II. A 200-mile radius represents a smooth 4/3 earth's radius radio horizon distance from an altitude of 20,000 feet. Most emitters capable of causing interference to the airport based ALGs are included within this radius although not all emitters within this radius would neccessarily cause interference. These figures and tables present the analytical results. Figures are presented of PRFs' versus frequency (including only emitters reporting a single tuned frequency) for each category of emitters present in the 200-mile radius from the airport. The width of each column in the figures is equal to the 3 dB emission bandwidth of the emitters contributing to the additive value of PRF which equals the height of the column. For example, on Figure 3-5 emitters nominally operating on 9080 MHz have emission spectra that may be grouped into three bandwidth categories. Transmitters at that frequency generate 7,000 pps with 4 MHz bandwidths, 3,000 pps with 3.5 MHz and 3,000 pps with a bandwidth of 2.5 MHz. Thus the total height of the column is 13,000 pps. It should be emphasized that the total PRF value is nothing more than the additive total. The received power levels of the pulses are distributed over a wide range. The final ALGS receiver parameters will determine a threshold level. Not illustrated on the graphs is frequency stability. MIL-STD-469 tolerances for the 9 to 9.2 GHz frequency range are ±.025 percent of operating frequency for crystal-or equivalently controlled radars and ± .125 percent for all other radars. TABLE 3-6 lists the characteristics of emitters that failed to report a tuned frequency. Figure 3-7 is a graph of emitter distances within 200-miles of JFK Airport.

The AN/TPN-19 Radar

The AN/TPN-19 Precision Approach Radar (PAR) will operate in airport environments within the 9.0 to 9.2 GHz band.

It is estimated that 120 AN/TPN-19 Ground Controlled Approach (GCA) Systems will be deployed worldwide at air bases beginning October 1972. The AN/TPN-19 PAR will operate with 250 kw peak output power with an option to reduce the output level by 15 dB during clear weather.

TABLE 3-3
PRIMARY EMITTERS IN 9.0 TO 9.2 GHz BAND

Group	Pulsewidth (μs)	Power (kW)	PRF Pulses per Second	Nomenclature
1	.18	45	1800	AN/CPN 4A, AN/FPN 16 AN/MPN 13, AN/MPN 14 AN/CPN 4, AN/CPN 48 AN/CPN 4C, AN/FPN 16A AN/FPN 22, AN/FPN 48 AN/FPN 49, AN/FPN 50 AN/GSN 2, AN/MPN 11 AN/MPN 11A, AN/MPN 11B AN/MPN 11C, AN/MPN 11D AN/MPN 11F, AN/MPN 15 AN/MPN 16, AN/MPN 17A AN/MPN 18
2	.18	45	5500	Same as Group 1
3	.5	35	2000	AN/FPN 1, AN/FPN 1A AN/FPN 2, AN/FPN 21
4	.5	25	2400	AN/MPN 5A, AN/FPN 28 AN/FPN 28A, AN/MPN 5 AN/MPN 5B, AN/UPN 10
5	.5	50	1500	AN/FPN 33
6	.18	50	1500	AN/FPN 33 MKIVC
7	.6	50	1500	AN/FPN 33 MKIVC
8	.18	150	1500	AN/FPN 36, AN/TSQ 60
9	.18	150	1500	AN/TSQ 60
10	.18	150	636	AN/FPN 36 MKIVC
11	.6	150	636	AN/FPN 36 MKIVC
12	.12	200	1500	AN/FPN 40, AN/FPN 40A
13	.6	200	1500	AN/FPN 40, AN/FPN 40A
14	.5	45	2000	AN/MPN 1, AN/MPN 1A AN/MPN 1B, AN/MPN 1C AN/MPN 3
15	.25	60	4000	AN/SPN 8, AN/SPN 8A
16	.2	200	1200	AN/TPN 8, AN/SPN 35 AN/TPN 14, AN/TPN 18 AN/SPN 35A, AN/TPN 8A
17	.8	200	1200	Same as Group 16
18	.55	160	1500	AN/TPN 12A, AN/TPN 17
19	.02	150	1500	AN/TSN 1
20	.6	150	1500	AN/TSN 1
21	.5	22	2000	PAR-1
22	.24	35	2400	PAR 2
23	.25	35	4000	PAR 2

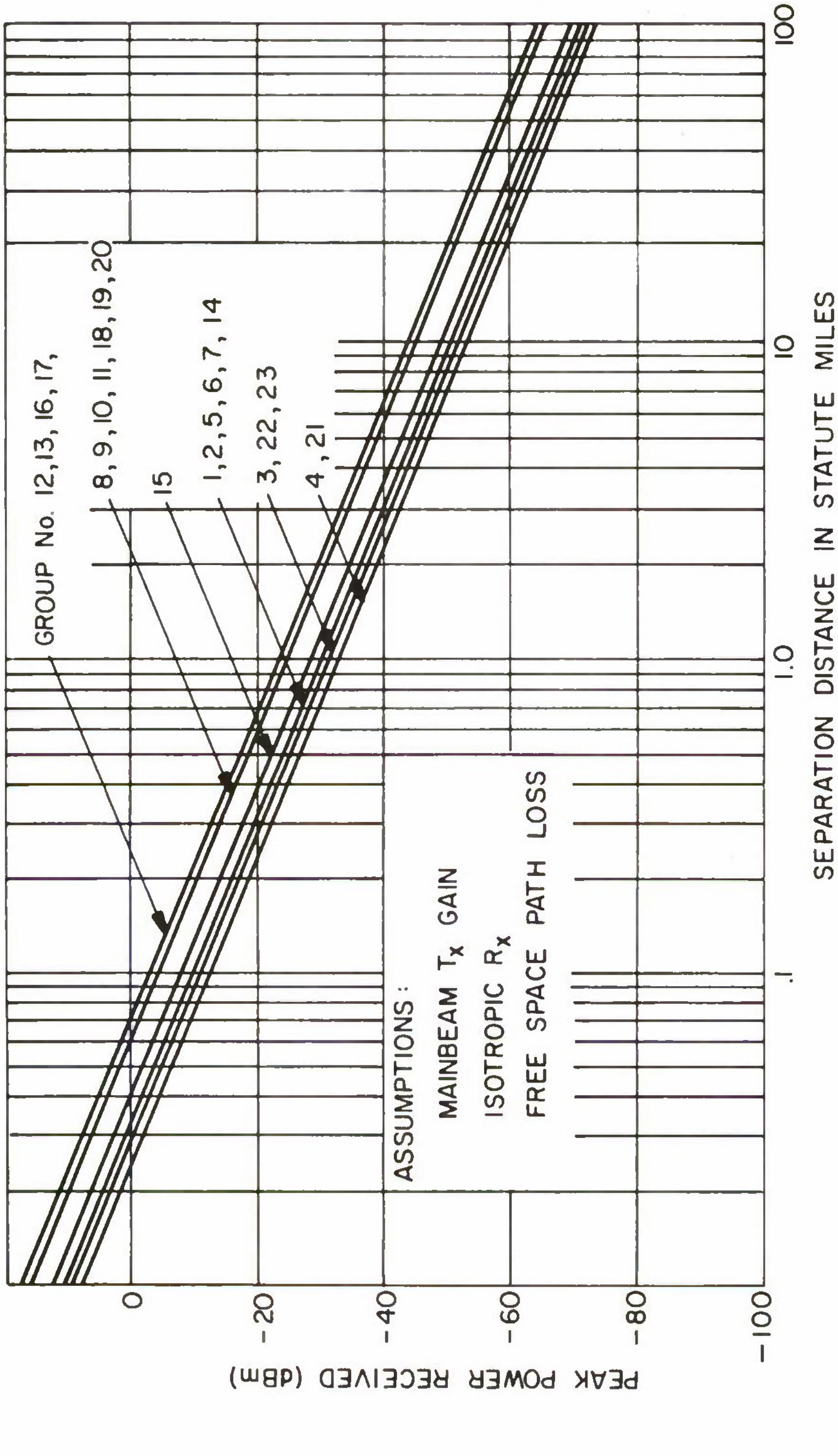

Figure 3-3. Peak Power Seen at an Isotropic Antenna as a Function of Separation Distance from Designated Transmitters (Free Space Propagation Loss Assumed)

TABLE 3-4
PRIMARY EMITTER GROUPED BY PULSEWIDTH

Category	Groups Comprising Category	Average Pulsewidth (μs)	Average 3 dB Emission Bandwidth (MHz)	Pulsewidth Range (μs)
A	1, 2, 6, 8, 10, 12, 16	0.18	6.0	0.12 to 0.2
B	3, 4, 5, 7, 9, 11, 13, 14, 17, 18, 20, 22	0.6	4.0	0.5 to 0.8
C	15, 21, 23, 24	0.25	2.0	0.24 to 0.25
D	19	0.02	50.0	0.02

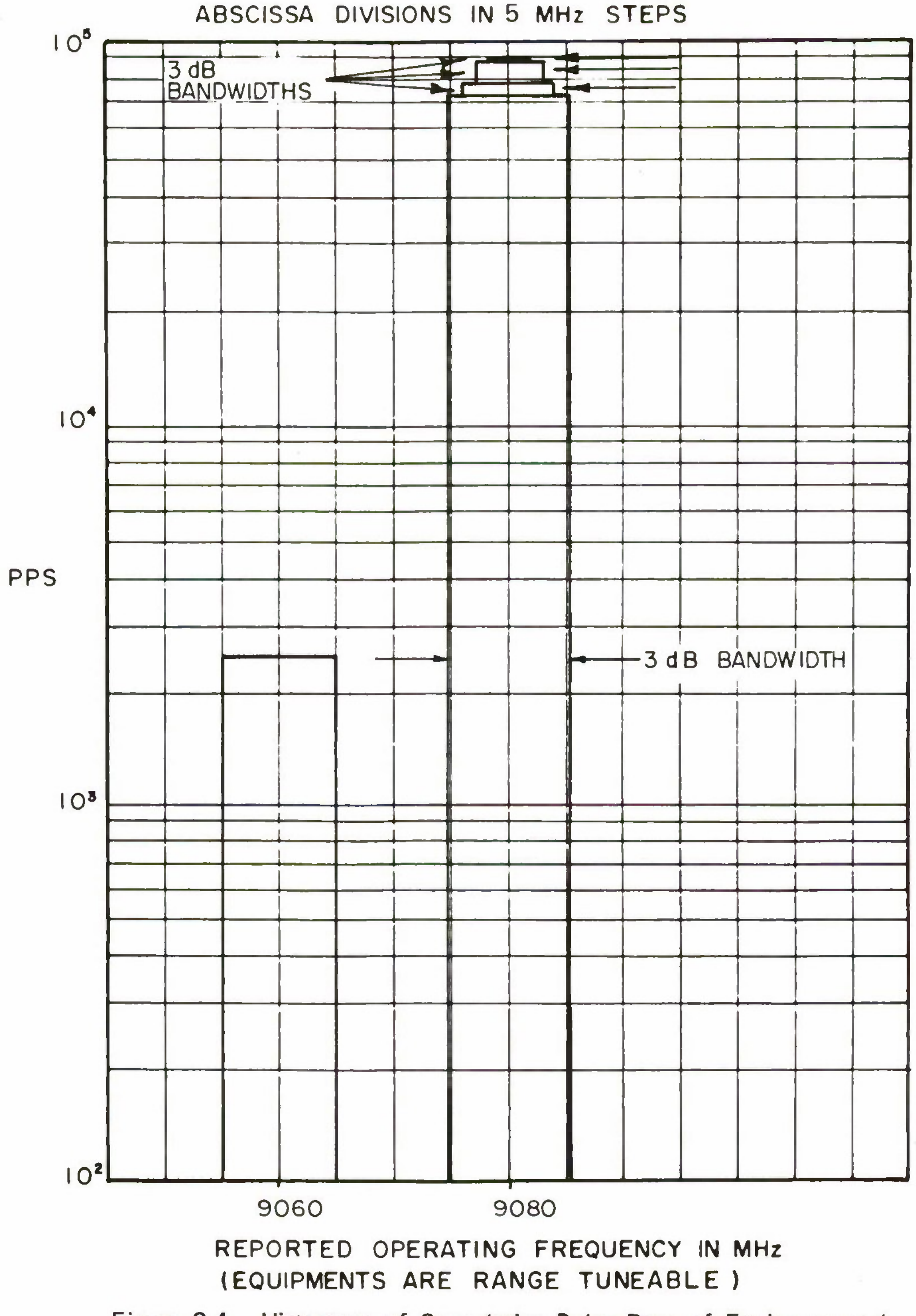

Figure 3-4. Histogram of Cumulative Pulse Rate of Environmental Transmitters at JFK, NYC Category A, 0.12 – 0.2 μs Pulses

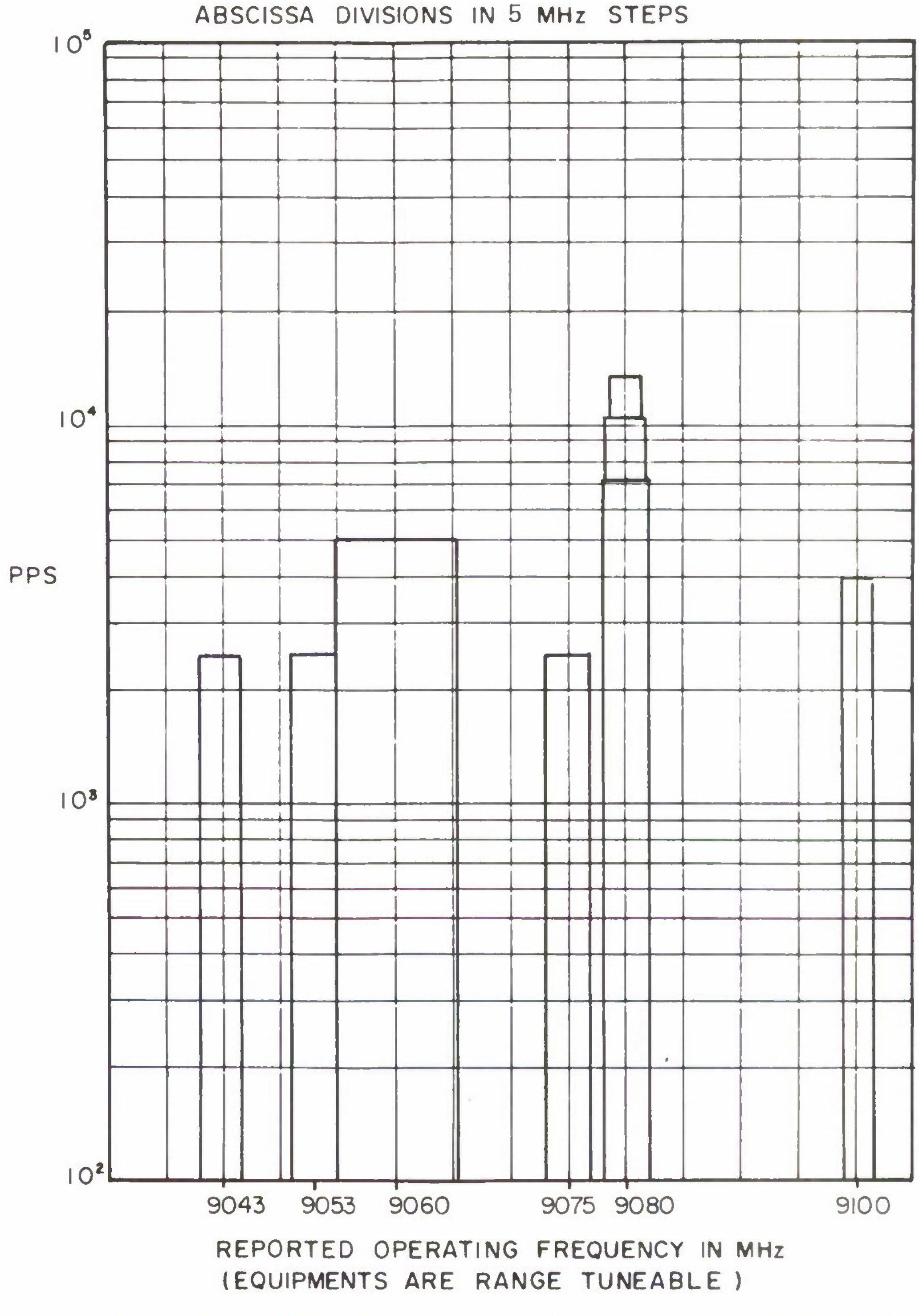

Figure 3-5. Histogram of Cumulative Pulse Rate of Environmental Transmitters at JFK, NYC Category B, 0.5 – 0.8 μs pulses

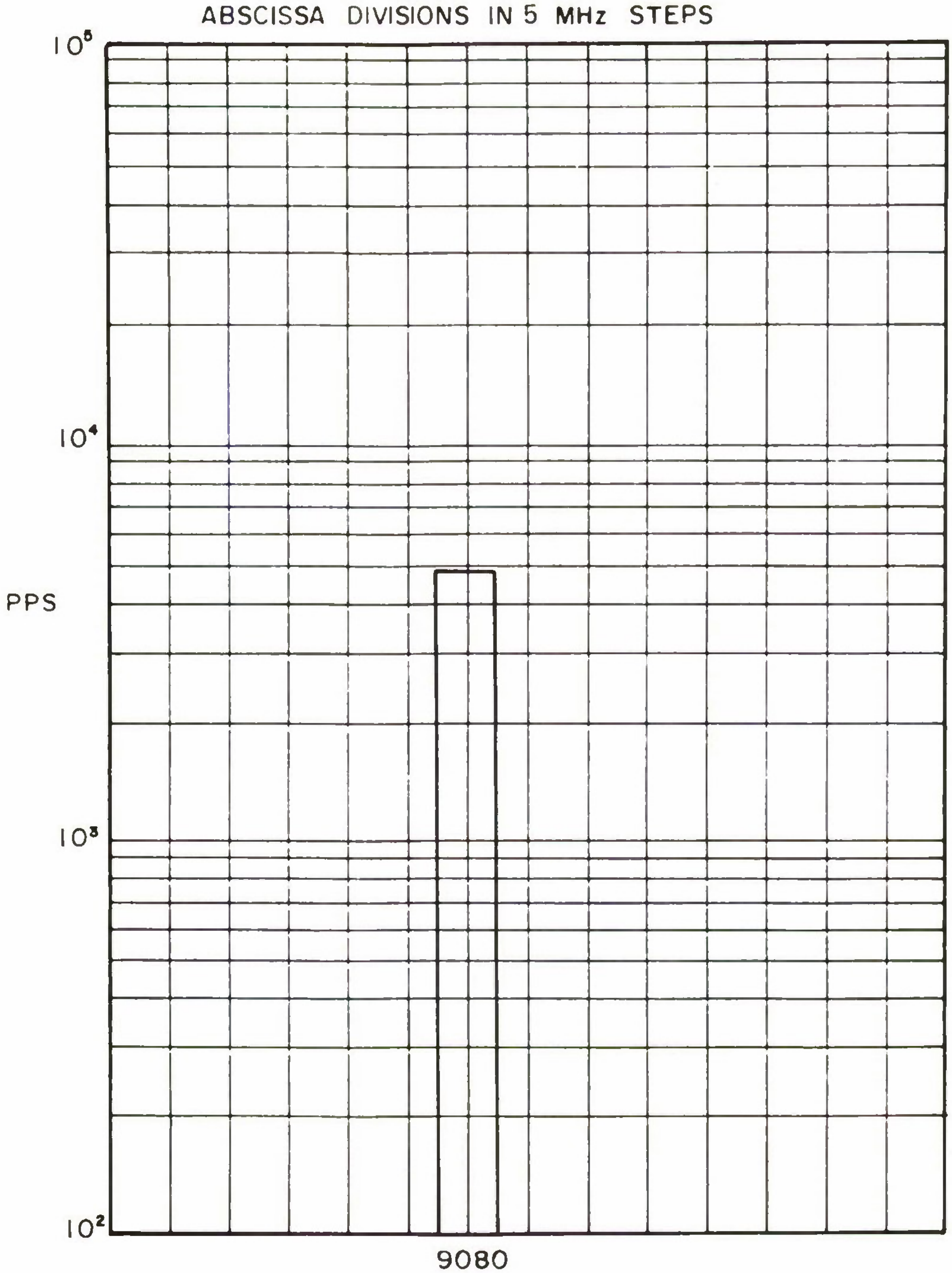

Figure 3-6. Histogram of Cumulative Pulse Rate of Environmental Transmitters at JFK, NYC Category C, 0.24 – 0.25 μs pulses

TABLE 3-5
EMITTERS NOT REPORTING FIXED FREQUENCY
(JFK AIRPORT ENVIRONMENTS)

Category	Frequency Range of the Emitter (MHz)	PRF (pps)	Transmitter Bandwidth (MHz)
A	9080 to 9110	5500	11
	9080 to 9110	5500	11
B	NONE		
C	9000 to 9100	1000	8
	9000 to 9160	2400	4.8
	9000 to 9160	2400	4.8

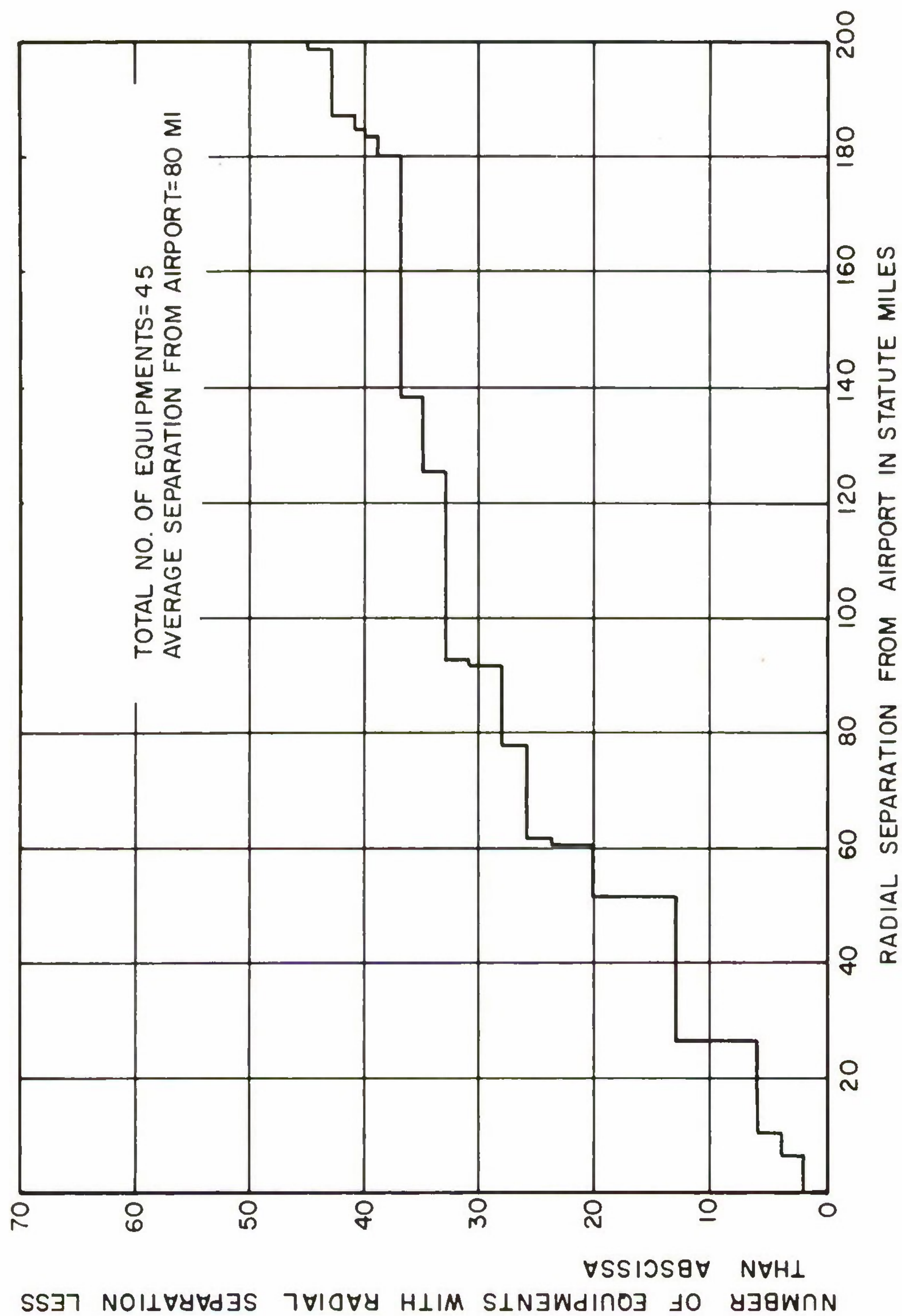

Figure 3-7. Distribution of Emitters within 200 Miles of JFK International Airport

The mainbeam of the AN/TPN-19 is a pencil beam; its gain is 42 dB relative to an isotropic radiator. The mainbeam axis scans 20° in azimuth and 7° or 14° in elevation. The antenna may also rotate, to cover more than one approach (runway).

The AN/TPN-19, PAR has two operational modes which are time interlaced. These modes are track and search.

The track-mode transmission consists of one microsecond pulses each linearly FM modulated over 180 MHz. The resulting bandwidth of 180 MHz covers effectively the entire 9.0 to 9.2 GHz range with a +60 dBm/MHz (at transmitting antenna terminals) peak spectral density. Track pulses are transmitted at an average rate of approximately 3,700 pps, with short bursts of 25,000 pps.

The search mode uses one microsecond double-frequency pulses. Two continguous .5 microsecond single-frequency pulses comprise a 1.0 microsecond double-frequency pulse.

Combinations of four frequencies taken two at a time are employed resulting in four frequency bands, these each have a 2 MHz bandwidth (frequency stability is rated .025 percent). Search pulses are transmitted at an average rate of 1,600 pps at each of four frequencies.

Figure 3-8 gives the peak spectral density in dBm/MHz that appears across the entire 9.0 – 9.2 GHz range as a function of separation distance from the AN/TPN-19 PAR. The figure assumes free space propagation path loss and an isotropic receiving antenna.

15.4 – 15.7 GHz Band Environment

In the 15.4 to 15.7 GHz band environment, there are three primary systems that may be operating during the post 1975 time frame. One system the AN/APS-113 (and the civilian version RDR-100) is an airborne navigation radar presently operating on both civilian and military aircraft along air routes. The second primary system, the AN/SPN-41 is an aircraft carrier mounted landing guidance system. The third primary system, the TALAR LAAS is a ground transportable landing guidance emitter being used primarily in non-CONUS areas.

The PRF's generated by the three emitters are constant for each equipment of that type in the environment. The PRF of the AN/APS-113 (or RDR-100) is 800 pps. Therefore if 10 aircraft in an environment are operating this equipment, an ALGS receiver may detect this PRF as 8,000 pps. The AN/SPN-41 (one per aircraft carrier) generates pulses at an average PRF of 3,000 pps. The TALAR LAAS generates pulses at a rate of 200,000 pps per transmitter.

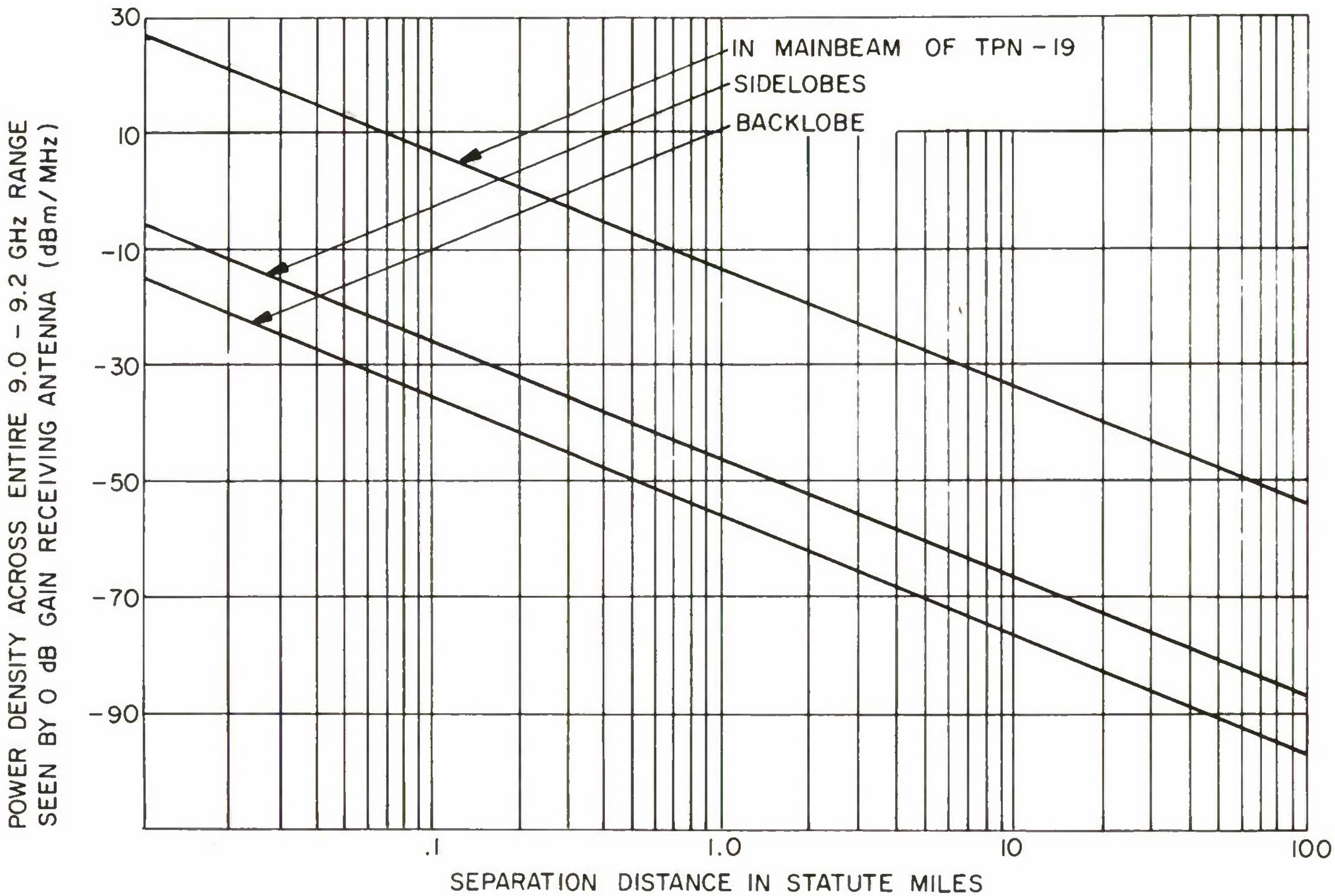

Figure 3-8. Peak Spectral Density Assuming Free Space Propagation Generated by Track Mode of AN/TPN-19

Presentation of the data on the 15.4 to 15.7 GHZ band also lends itself to graphical and tabular presentation. Discussion of the figures and table is given in the paragraphs that follow:

TABLE 3-6 shows the emitters, likely environments, pulse width, rated frequency stability, 3 dB emission bandwidth, whether the emitter is fixed frequency (F) or range tuned (R), and its operating frequency range.

Figure 3-9 shows peak power "available" to a victim as a function of separation from each emitter. When not in the interferer's mainbeam peak power will drop 30 dB for the APN-113, and the SPN-41 and 23 dB for TALAR.

FOREIGN USERS

General

The primary sources of information on international use were the International Frequency Registration Board (IFRB) documents of ITU and information provided by Service technique De La Navigation Aerienne (TABLE 3-7).

The information in these sources is limited in detail and not so comprehensive as the data in ECAC's data base. For example, in common geographic areas the IFRB records did not list many of the emitters listed in the ECAC's data base.

ITU International Frequency List

The following information was extracted from the ITU International Frequency List dated 1 February, 1969.

There are no significant items in the 5.0 to 5.25 GHz band.

In the 9.0 to 9.2 GHz band, there are 14 emitters registered worldwide. Some parameters are listed in TABLE 3-8.

TABLE 3-6
15.4 to 15.7 GHz BAND EMITTERS

Emitter	Where Found	Pulsewidth (μs)	Stability (MHz)	Emission 3 dB (MHz)	Tuning (F/R)
AN/APS-113	Along air routes (civilian and military aircraft)	1.5	37	1.4	R(200 MHz)
AN/SPN-41	On aircraft carriers (one per carrier)	0.3	4.5	2.0	R(300 MHz)
TALAR LAAS	Tactical (ground transportable)	2.5	7.0	5.0	R(50 MHz)

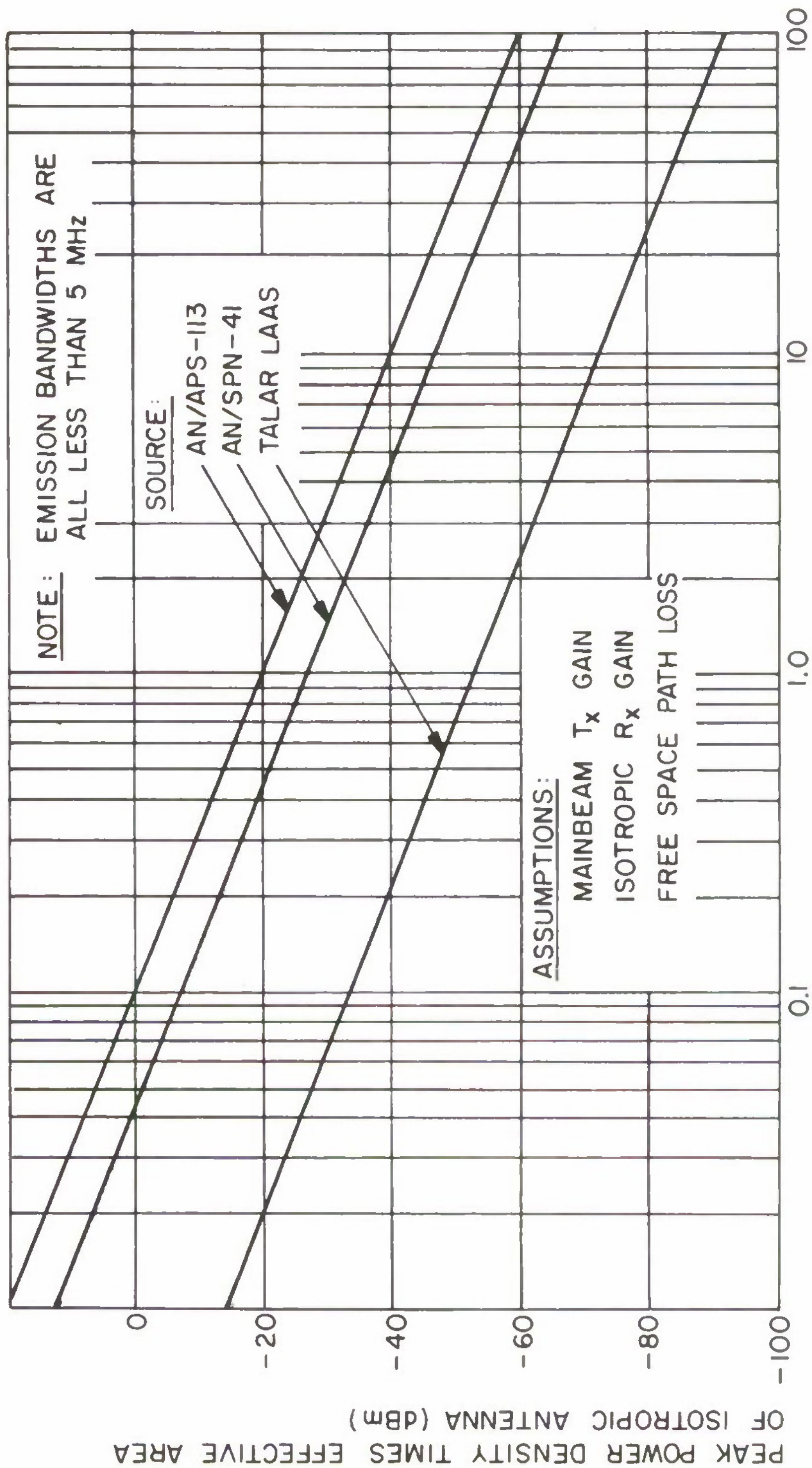

Figure 3-9. Peak Power Density Times Effective Area of Isotropic Antenna for K_u Band Equipments

TABLE 3-7 (Sheet 1 of 3)
INTERNATIONAL USE OF THE BANDS

MHz 1	Allocation of the Service 2	Notes 3	Actual and Planned Optional Uses for Aeronautical Radio Navigation 4	Additional Information Included for Experimental Projects 5
5000 to 5250	Worldwide Table Aeronautical Radio Navigation 352A, 352B	352A The bands 1540 to 1660 Mc/s 4200 to 4400 Mc/s, 5000 to 5250 Mc/s and 15.4 to 15.7 Gc/s are reserved on a world-wide basis, for the use and development of airborne electronic aids to air navigation and any directly associated groundbased or satellite-borne facilities.	France: Compatible ILS landing system and landing system ADAC/ADAV (distance measuring) Compatible ILS Type CSF SYDAC band 5001-5005 MHz (runway alignment) band 5221.6-5228.4 MHz (glide path) (Much like the ILS in 108-112 and 328.6-335.4 MHz)	U.K. Studies progressing on microwave approach and landing systems France: In process of constructing aeronautical radio communication satellite (including satellite-earth station)
		352B The bands 1 540-1 660 Mc/s, 5 000-5 250 Mc/s and 15.4-15.7 Gc/s are also allocated to the aeronautical mobile (R) service for the use and development of systems using space communication techniques. Such use and development is subject to agreement and coordination between administrations concerned and those having services operating in accordance with the Table, which may be affected.	Switzerland: Used in conformance with the ITU regulations.	Relay link between DIOSCURE and earth station 5010-5050 MHz ground-satellite 5210-5250 MHz satellite-ground

TABLE 3-7 (Sheet 2 of 3)

MHz 1	Allocation of the Service 2	Notes 3	Actual and Planned Optionel Uses for Aroneutical Radio Navigation 4	Additional Information Included for Experimental Projects 5
9000 to 9200	Aeronautical Radio Nevigation Radio-locetion (Secondary) 346,397	346 Tha use of tha bands 1300 to 1350 Mc/s, 2700 to 2900 Mc/s and 9000 to 9200 Mc/s by the aeronautical radionavigation service is restrictad to ground-based redars and, in the future, to associated airborne trans-ponders which transmit only when actuated by radars opereting in the same band. 397 In Belgium, France, the Netherlands end the F.R. of Germany, the band 8825.9225 Mc/s is also allocated to tha maritime radionavigation service for use by shore-based radars.	Austria: PAR at WIEN/Schwechat Caneda: PAR France: GCA, 3cm radar landing systam (sea column 5 as well). West Garmany: PAR India: PAR Ireland: PAR Japan: PAR Newfoundland: PAR Norway: PAR Singapore: (cf. band 8500-8750 MHz) South Africa: PAR on 9080 MHz U.K.: GCA	France: GCA, 3cm redar landing system in developmant Note also that in ITU Region 1, certain (PAR) precision radars function on 9300 MHz (cf No. 399RR)

TABLE 3-7 (Sheet 3 of 3)

MHz 1	Allocation of the Sarvice 2	Notas 3	Actual and Plenned Optlonel Uses for Aronautical Redlo Navigation 4	Additional Information Included for Experimentel Projects 5
15,400 to 15,700	Aeronauticel Radio Nevlgetion 352A, 352B, 407	352A Tha bands 1540 to 1660 Mc/s, 4200 to 4400 Mc/s, 5000 to 5250 Mc/s and 15.4 to 15.7 Gc/s ara reserved on a world-wide basis, for the usa end development of airborne electronic aids to air navigation and eny directly associated groundbased or satellite-borne facilities. 352B Tha bends 1540 to 1660 Mc/s, 5000 to 5250 Mc/s and 15.4 to 15.7 Gc/s are also allocated to the aaroneutical mobila (R) service for the use and development of systems using space communicetion techniques. Such use and devalopment is subject to agreement and coordination between administrations concerned and those hevlng services operating In accordance with the Table, which may be affected.	Austrelia: Mateorological reder, airborna on 15.5 GHz France: Airborne Navigation Radar on helicopters Italy: Meteorological redar on 15.5 GHz Swltzerland: Use of the band conforms to tha ITU regulations.	Japan: Aeroneuticel Radio Navlgation under devalopment

TABLE 3-8
ITU 9.0 TO 9.2 GHz INTERNATIONAL FREQUENCY LIST

	European Area							N & S America			Far East			
Emitter Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Emission Class	PO	PO	PO	PO	PO	PO	PO	PO	PO	PO	PO	PO	PO	PO
Bandwidth (MHz)	20	4	12	10	10	50	50	50	----	40	34	12	.5	44
Power (kW)	10	50	50	150	20	50	50	50	----	----	45	15	50	----
Antenna Gain (dB)	41	----	34	----	----	40	40	40	----	----	----	----	20	----
Effective Radiated Power (kW)	----	----	----	----	----	----	----	----	500	.001	----	----	----	45

SECTION 4

RESULTS OF STUDY OF ITG (9.0 to 9.2 GHz) SYSTEM IN JFK ENVIRONMENT

ITG SYSTEM-CONCEPT REQUIREMENTS

The ITGS system is an ITT Gilifillan concept of how the ALGS requirements might be achieved. The ITGS system has unique frequency-utilization requirements for a single channel. A single channel consists of three ground-to-air links and one air-to-ground link. See Figure 4-1. Each link requires a different frequency "slot", and the four slots of a given channel must have a fixed frequency separation due to equipment considerations. (The four slots span 50 MHz.) If one of the four links of a channel is incapacitated by electromagnetic interference, the channel is inoperative.

OBJECTIVE

The objective of this analysis was to aid in estimating the channels available in the 9.0 – 9.2 GHz range to an ALGS system. Placement of the ITGS system in the 1970 JFK Airport environment was simulated for purposes of this analysis. Details of the analysis are given in APPENDIX II.

RESULTS

1970 channel occupancy associated with JFK runway 13 is shown on Figures 4-2 and 4-3. The 40 ITGS system channels are on the abcissa while the ordinate shows subsystem components of the four links comprising a channel. The letters preceding the parenthetical letter indicate the ITG function of the link: elevation, azimuth, or DME information. The letter within parentheses indicates whether the equipment comprising that end of the link is ground based or airborne. An X in a box means that subsystem component may experience or supply a positive INR (Figure 4-2) or at least a + 10 dB INR (Figure 4-3) from or to at least one primary user.

For example, channel 4 (Figure 4-2) is estimated to experience a positive INR in its airborne azimuth and DME receivers, but its DME ground-based transmitter may cause at least one primary user in the environment to experience a positive INR.

The net result of this process is that 10 channels are "clear" using a 0 dB INR threshold increasing to 12 "clear" channels when a + 10 dB INR threshold is used. This process acknowledged only inband interactions (9.0 – 9.2 GHz).

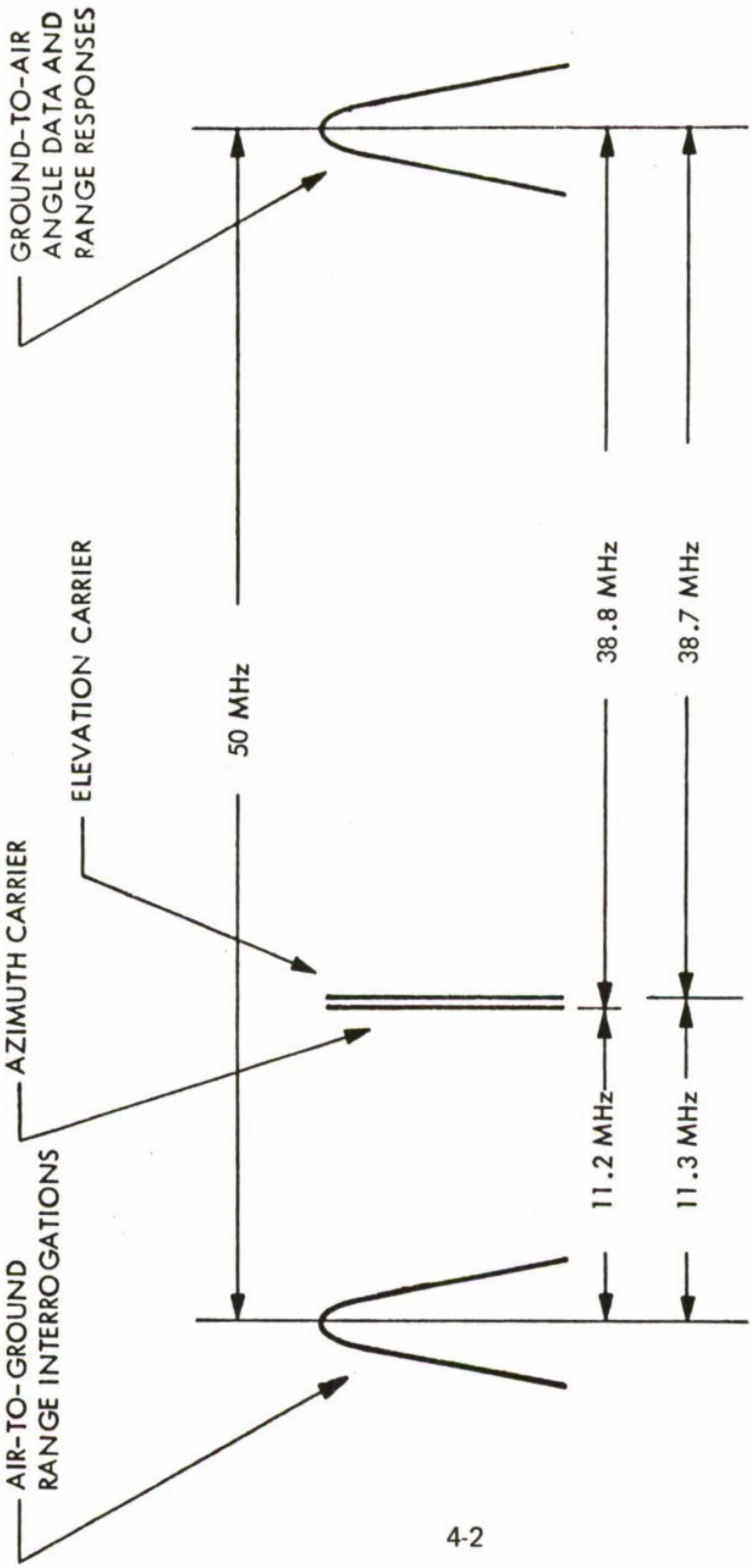

Figure 4-1. Assigned Frequency Spacings

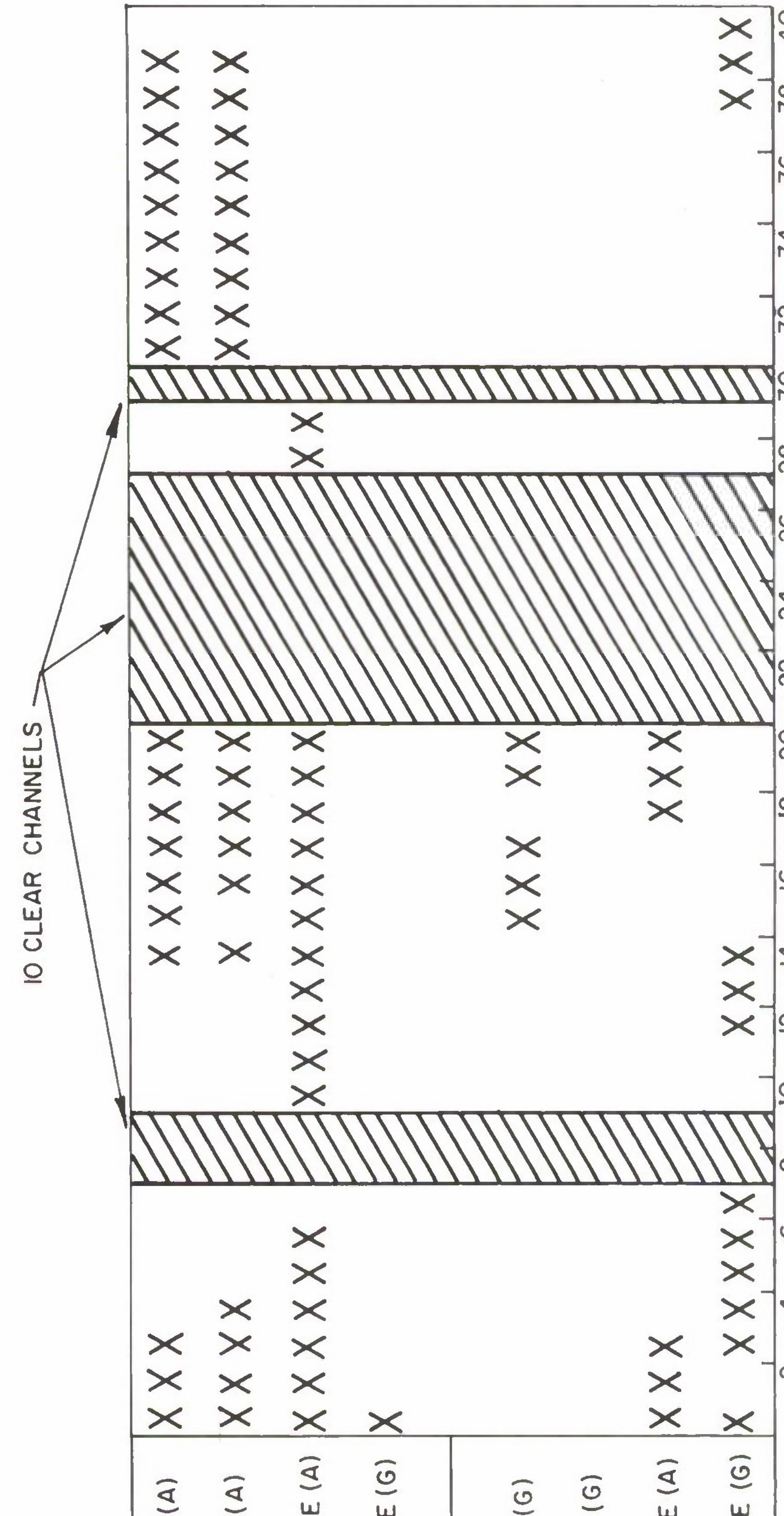

Figure 4-2. ITG System Channel Occupancy in JFK-Runway No. 13, Environment allowing 0 dB INR Before Declaring Occupancy

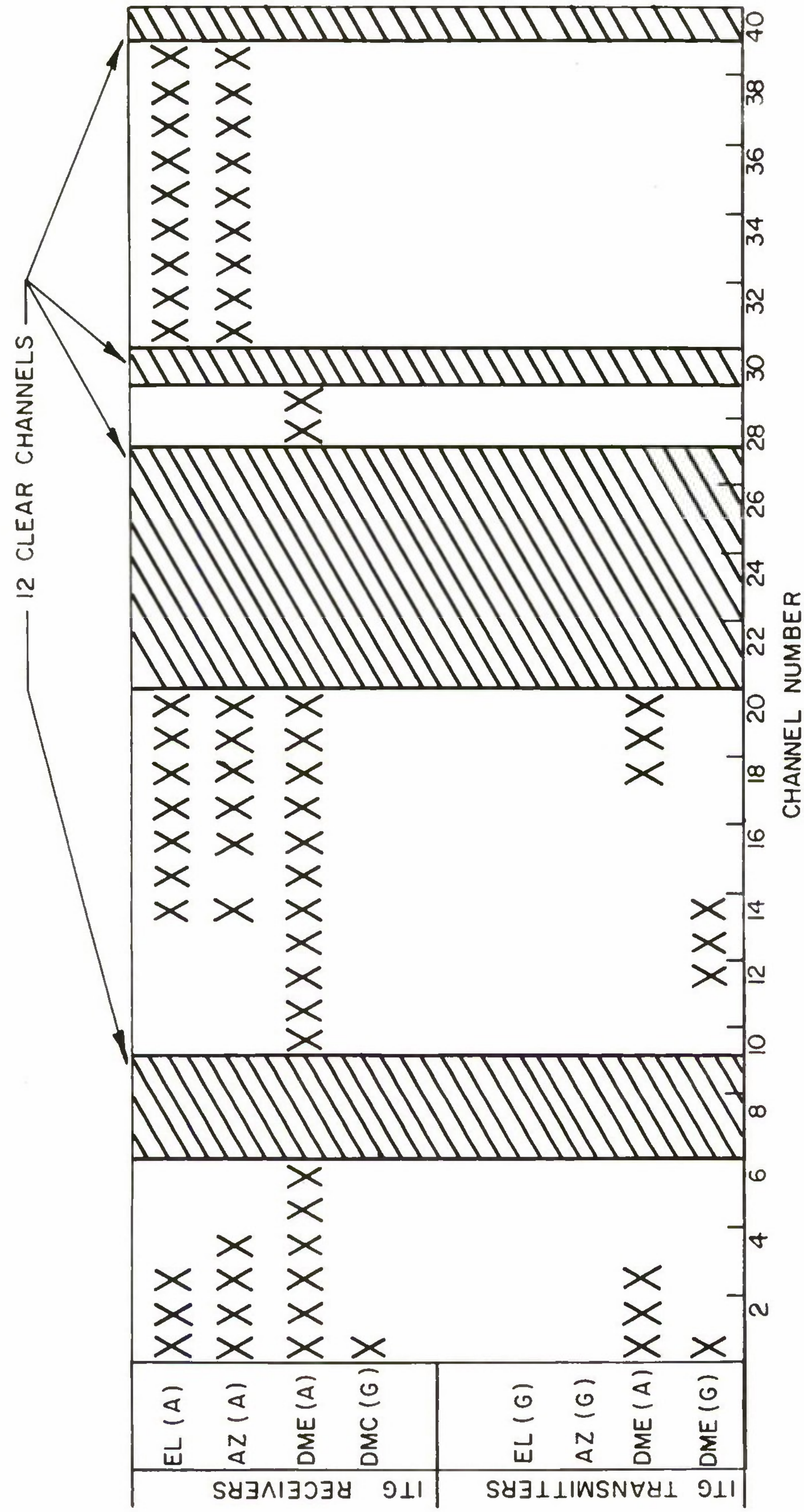

Figure 4-3. ITG System Channel Occupancy in JFK-Runway No. 13, Environment allowing +10 dB INR Before Declaring Occupancy

These results are predicated on the assumption that interference is present when INR is positive or + 10 dB. This assumption may be pessimistic.

Formulating generalizations, based on this limited study, regarding spectrum availability in the 9.0 to 9.2 GHz band, and independent of ALGS geographic location or system design should be done with caution.

Projected use of the band by military services indicates that a primary user of the band will continue to be GCA equipment.

PROPOSED ITGS SYSTEM MODIFICATIONS

Proposed modifications (Reference 3) to the ITGS system concept by ITT Gilifillan included the use of hard limiting (Dicke Fix), increasing the number of carrier frequencies for a given channel from 4 to 5, sharing the available 200 MHz among 25 channels, instead of 40, and use of quadruple time sharing (25 percent duty cycle) channels to reach a maximum capacity of 100 channels for the ITGS.

Time did not permit detailed consideration of the effects of these changes. The following rather obvious comments are however pertinent:

1. The emission bandwidths of the present X-band environment are approximately the same as the ITG DME emissions, reducing the advantages in interference suppression available with a Dicke Fix.
2. Increasing the number of carrier frequencies to five will reduce the number of available channels due to increased possibilities for interactions.
3. The reduction of the number of frequency channels from 40 to 25 with its resulting increase in frequency occupancy per channel, increases the chances of interaction with the environment per channel.
4. Quadruple "time-sharing" may reduce the degree of interaction with an environmental equipment operating on the same frequency.

SECTION 5

RESULTS OF ALGS CHANNEL REQUIREMENTS ANALYSIS

GENERAL

A critical design parameter of the future ALGS is the number of channels to be implemented in the hardware design. The objective of this section is to provide estimates of channel requirements dependent upon the following three factors:

1., The total air terminal complex requiring ALGS service;
2. The type of ALGS service provided at each runway, and
3. The channel assignment constraints.

AIR TERMINAL COMPLEXES

Data for two future air terminal complexes were submitted by the FAA for analysis. The first consisted of airports in the Southwest region of the U.S. and second consisted of airports in Western Europe. The data identified runways in these areas potentially requiring ALGS service and specified the location, orientation and whether one-way or two-way service would be required. The runways were further broadly classified as to the amount of air traffic handled (high, medium, or low) and the predominate type of aircraft (air-carrier, general aviation, military, or VSTOL).

U.S. Air Terminal Complex

A four state area in the Southwestern region of the U.S. was selected as representing a high air traffic area. The four states selected (California, Arizona, Nevada, and Utah) are indicated in Figure 5-1. The area of southern California (Los Angeles area) is of particular concern. The surrounding area is included since it has some impact on the assignment of channels in the Los Angeles area.

In the four state area, 219 airports with a total of 352 runways were identified as potential candidates for ALGS service. The runways were classified as follows:

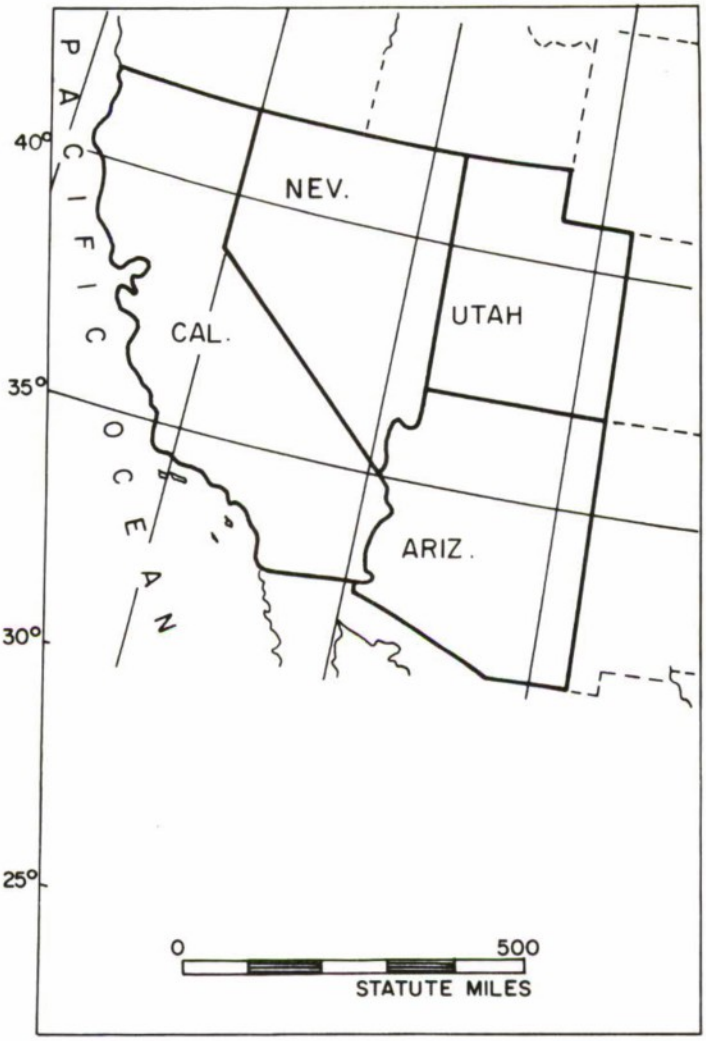

Figure 5-1. Four State Area

High-Air-Traffic Air-Carrier	35
Medium-Air-Traffic Air-Carrier	39
Low-Air-Traffic Air-Carrier	23
High-Air-Traffic General Aviation	58
Medium-Air-Traffic General Aviation	122
Low-Air-Traffic General Aviation	54
Low-Air-Traffic Military	15
Medium-Air-Traffic VSTOL	6
Total Runways	352

Of the 352 runways, 86 were specified as providing two-way service and the remainder providing one-way service.

European Air Terminal Complex

The European air terminal complex contained airports operated in France, Switzerland, Italy, Belgium, Netherlands, Luxemburg, Germany and Great Britain. Airport locations ranged from 45° to 55° N. in latitude and from 5° W. to 10° E. in longitude as indicated by the dashed lines in Figure 5-2.

In this area, 246 airports with a total of 272 runways were identified as potential candidates for ALGS service. The runways were classified as follows:

Medium-Air-Traffic Air-Carrier	25
Low-Air-Traffic Air-Carrier	187
High-Air-Traffic General Aviation	22
Medium-Air-Traffic General Aviation	38
Total Runways	272

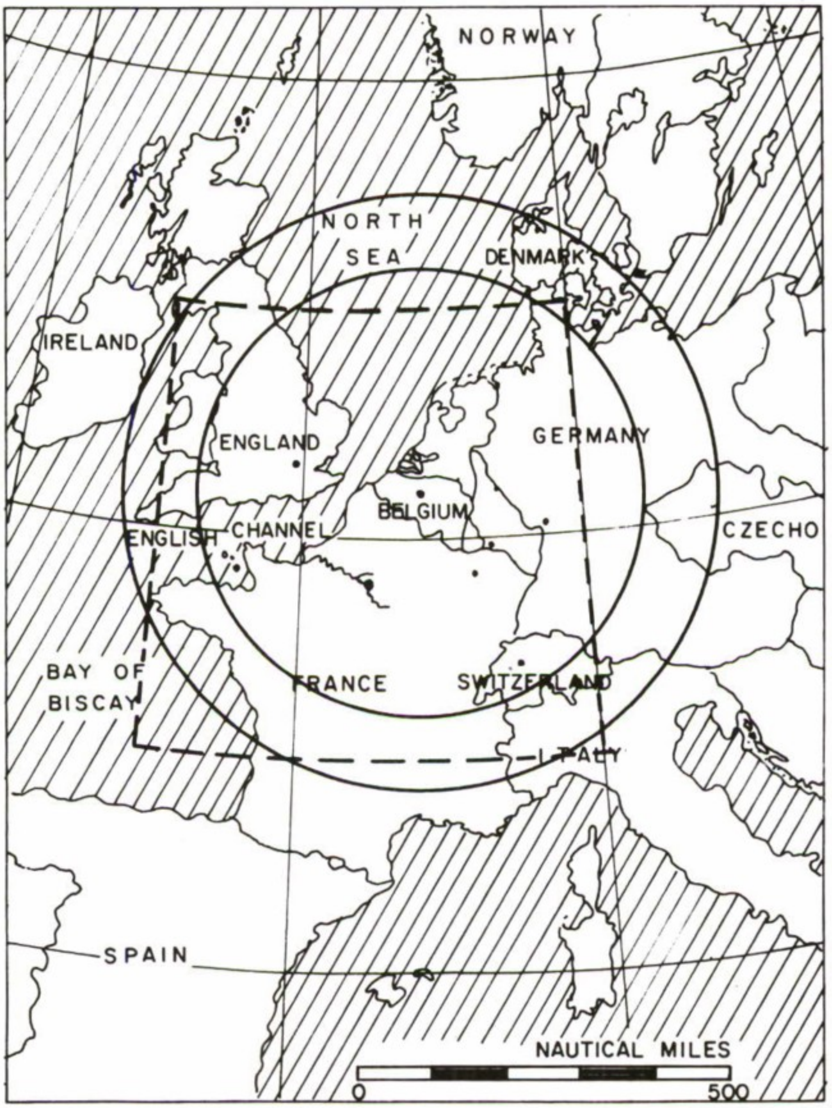

Figure 5-2. European Area

Of the 272 runways, 121 were specified as providing two-way service and the remainder providing one-way service.

ALGS SERVICE

Three alternative implementations of ALGS service on a runway were considered. These were classified as:

One-Way System (No Back-Course)

For this case, each runway specified for one-way service is provided with ALGS service in the appropriate direction, however, no back-course guidance for missed approaches is provided. Runways requiring two-way service are provided with an ALGS for each direction.

One-Way System (With Back-Course)

For this case, each runway specified for one-way service is provided with ALGS service in the appropriate direction, and furthermore, equal back-course service is provided for missed approaches. Runways requiring two-way service are provided with an ALGS for each direction. Each of these systems also provides back-course service.

Two-Way System

For this case each runway is provided with a single ALGS which provides equal service in both directions.

For each of these system alternatives, angular coverages of $\pm 40^\circ$, $\pm 60^\circ$ and $\pm 90^\circ$ with respect to the runway center-line were considered. These angular coverages also extend to back-course service if applicable.

An exception was made to the above service alternatives for runways classified as low-air-traffic general aviation. All such runways were considered always to be equipped with One-Way System (No Back-Course) providing $\pm 20^\circ$ angular coverage.

CHANNEL ASSIGNMENT CONSTRAINTS

In estimating channel requirements the following channel assignment constraints were employed:

1. A circular airport zone (AZ) was specified for each ALGS. For the low-air-traffic general aviation facilities, the AZ radius was set at 10 nmi. For all other facilities a 25 nmi radius was used.

2. The 10 and 25 nmi AZs were required to be at least 10 and 25 nmi (respectively) from each co-channel facility, and at least 100 and 200 nmi (respectively) from each co-channel facility if within the angular coverage zone of the latter.

3. All ALGSs at the same airport must have different channels.

The above channel assignment constraints are referred to as the full-distance constraints. Half-distance constraints were also employed. In this case the 100 and 200 nmi distances were reduced to 50 and 100 nmi (respectively); all other constraints were unchanged.

ESTIMATES OF CHANNEL REQUIREMENTS

The analytical procedure employed in estimating channel requirements is based on graph theoretic concepts. In particular, the classical node-coloring problem of graph theory and the notion of chromatic numbers are related to the problem of determining the minimum number of distinct channels required for a system under a given set of constraints. This method of analysis, including the basic node-coloring algorithms, is discussed in detail in Reference 5.

Estimates of the minimum number of channels required for the ALGS based on future U.S. (four state area) and Western Europe air terminal complexes were obtained. These estimates were obtained for several alternative concepts of ALGS service, angular coverages and channel assignment constraints as previously discussed. The results are summarized in TABLE 5-1 and TABLE 5-2.

It should be emphasized that these are minimum channel requirements under the specified conditions. Departures from these estimates may be expected due to uncertainties in specifying the future airport/runway complex, special operational requirements, propagation anomalies, etc. Furthermore, an optimal assignment to an evolving airport complex may imply substantial revision to the existing assignments from time-to-time as new ALGS facilities are introduced. To minimize the need to revise assignments, an excess of channels, perhaps 10 to 20 per cent, might be necessary.

TABLE 5-1
MINIMUM ALGS CHANNEL REQUIREMENTS
BASED ON THE U.S. AIR TERMINAL COMPLEX

	Minimum Channel Requirements					
Type of ALGS Service	One-Way (No Back-Course)		One-Way (With Back-Course)		Two-Way (One Per Runway)	
Number of ALGS Facilities	438		438		352	
Assignments Constraints	Half Distance	Full Distance	Half Distance	Full Distance	Half Distance	Full Distance
Angular Coverage ± 40	91	98	107	119	75	85
Angular Coverage ± 60	96	105	126	144	87	103
Angular Coverage ± 90	111	122	133	157	92	113

NOTE:

219 Airports (Four State Area)
352 Runways

TABLE 5-2

MINIMUM ALGS CHANNEL REQUIREMENTS
BASED ON THE EUROPEAN AIR TERMINAL COMPLEX

Type of ALGS Service		Minimum Channel Requirements: One-Way (No Back-Course)		One-Way (With Back-Course)		Two-Way (One Per Runway)	
Number of ALGS Facilities		393		393		272	
Assignment Constraints		Half Distance	Full Distance	Half Distance	Full Distance	Half Distance	Full Distance
Angular Coverage	± 40	34	43	45	61	33	44
	± 60	39	53	59	91	42	63
	± 90	47	74	67	126	49	89

NOTE:

246 Airports (Western Europe)
272 Runways

SECTION 6

RESULTS OF STUDY OF ADJACENT CHANNEL IMPLICATIONS OF PAUL BUNYAN FORMAT

THE PAUL BUNYAN FORMAT

One of the system functions of the ALGS will be to provide range information. This function will be provided by the distance measuring equipment (DME). The signal format for the DME has yet to be selected. One proposed format is the Paul Bunyan Signal Format (see Reference 4).

In this proposed DME system, range information will be provided by the leading edge of a trapezoidal-pulse waveform. The DME accuracy, and required RF bandwidth versus pulse rise time to achieve this accuracy, are discussed in Reference 4. The Paul Bunyan discussion indicates a required RF-pulse rise time of 0.2 μs. The entire ranging-pulse waveform was structured as a pulse with a 0.2 μs rise time, 0.2 μs top and 0.2 μs fall time, repeating every 10 μs.

DME CHANNEL REQUIREMENTS

From the description of the signal waveform and consideration of receiver and transmitter frequency drift (in opposite directions), an adjacent channel situation was depicted. This depiction yielded minimum desired power and maximum undesired power within the passband of the desired receiver. Spillover from the adjacent channel accounts for undesired power within the receiver passband. This condition is illustrated in Figure 6-1. The desired to undesired power ratio was computed as 24.3 dB, as set forth in Reference 4. This ratio is a signal-to-interference ratio and applies to a situation where the receiver is receiving a desired and an undesired signal from two transmitters, each transmitting on one of two adjacent channels with the transmitting antennas near each other and radiating into a common volume.

OBJECTIVES

ECAC was tasked to analyze the implications of the Paul Bunyan Format and channel separation requirements in a deployed situation. The objective of this discussion is to determine the implications of a worst case deployment.

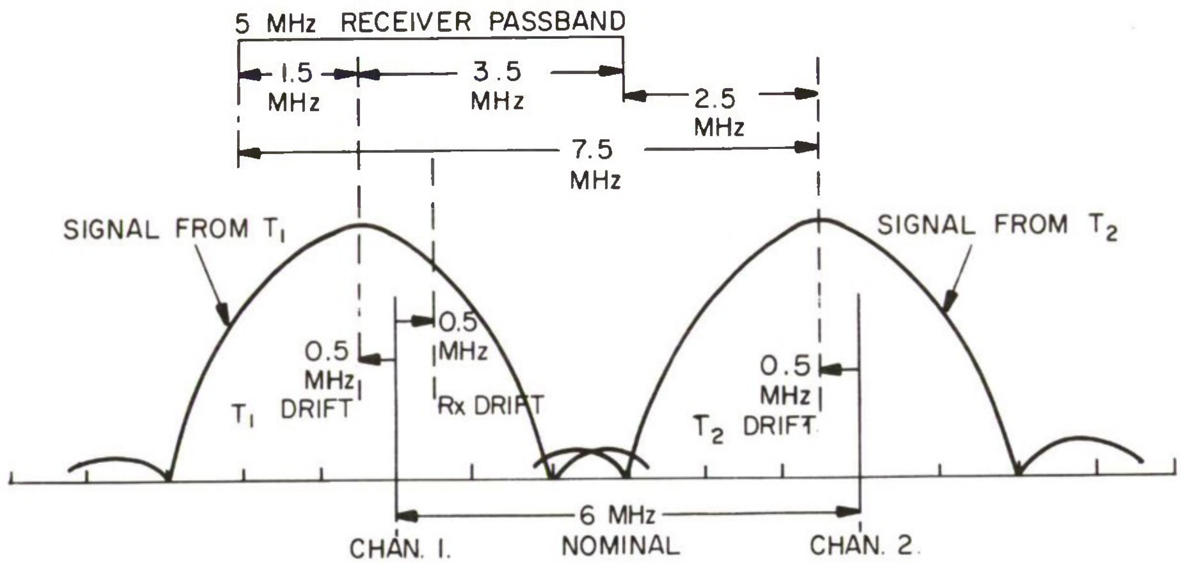

Figure 6-1. Desired Signal (from T_1) and Receiver, with Signal (from T_2) in Adjacent Channel. (Unfavorable Frequency Drift Conditions are shown)

In a specific configuration, the desired to undesired power ratio due to adjacent channel spillover can be less than 24.3 dB. For instance, suppose that an aircraft is in its approach pattern and within coverage of the desired transmitter and another DME transmitter (undesired adjacent channel). It is possible for the aircraft to be nearer the undesired transmitter, which is located at an airport about 16.5 nmi away, than the desired transmitter. This configuration is illustrated in Figure 6-2, where T_1 is the desired transmitter, T_2 the undesired transmitter and L the location of the aircraft.

ANALYTICAL APPROACH

Since it will yield worst case interference results, an elevation approach angle for high performance aircraft (2.5°) was chosen for this example. These distances and angles place the aircraft in the mainbeam of each transmitting antenna. Distance d_1 is given as 20 nmi. Knowing this and the approach angle, the aircraft altitude was computed as 5,300 feet and d_2 as 19,800 feet. From this computation of the distances, L to T_1 and L to T_2 yield 121,750 feet and 20,500 feet respectively. Free space progagation loss is given by 37 + 20 log F (MHz) + 20 log d (mi). Assuming that transmitting antennas are identical for T_1 and T_2 and that both transmissions are within the receiving antenna's mainbeam, propagation loss accounts for the difference between attenuation to one signal and attenuation to the other signal. The difference in propagation loss between L to T_1 and L to T_2 is

$$20 \log \frac{121{,}750}{20{,}500} = 15.45 \text{ dB}. \tag{6-1}$$

Thus, the signal from the desired transmitter is attenuated about 15.5 dB more than the signal from the undesired transmitter, and the signal-to-undesired adjacent-channel signal power ratio is reduced to 8.8 dB, instead of 24.3 dB.

SPECTRUM ANALYSIS

If the signal-to-interference ratio is to be kept around 20 dB, the center frequency of T_2 must be separated from that of T_1 by more than one channel. The following analysis shows the S/I ratio versus channel separation for the spectrum of the previously described waveform. In order to show this separation, the power density spectrum was computed in the following manner. If f (t) is an aperiodic function of duration τ with a transform F (ω), and if f_T (t) is a periodic function with period T described by repetition of f (t) every T seconds, $T > \tau$, it can be shown that the exponential Fourier Series coefficients are:

$$F_{Tn} = \frac{1}{T} F(\omega) \Big|_{\omega = n\omega_o = \frac{2\pi n}{T}} \tag{6-2}$$

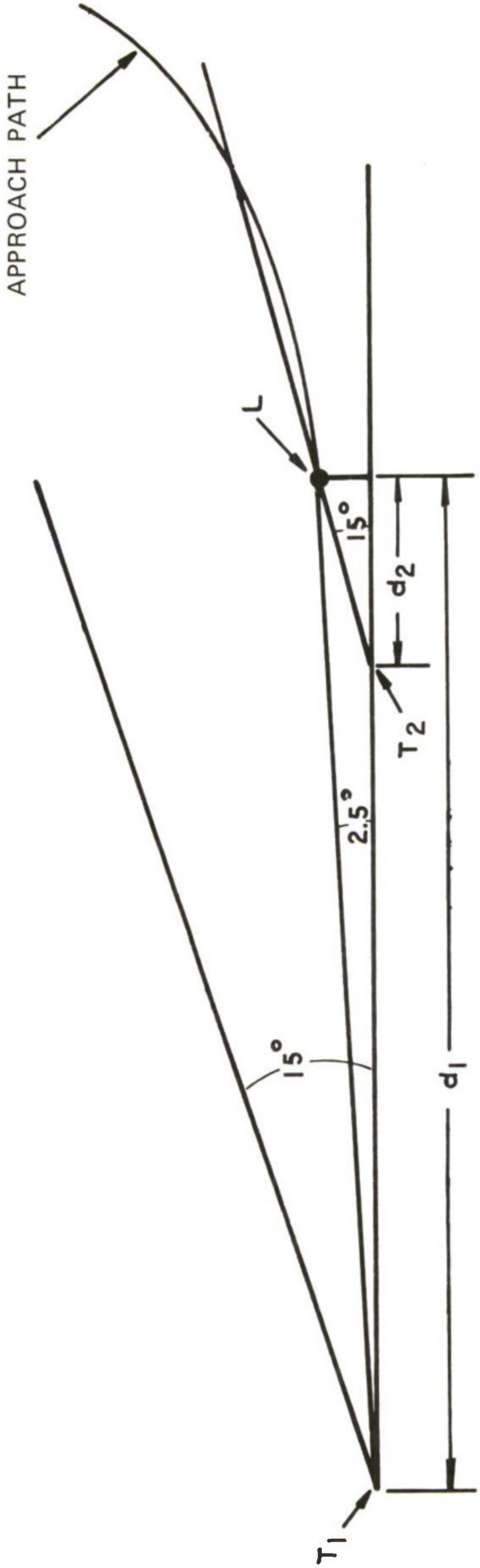

Figure 6-2. Diagram Depicting an EMC Situation where Transmitter T_2 is Interfering with a Signal Being Received from Transmitter T_1

also, the power density spectrum is

$$\Phi_T(\omega) = \frac{2\pi}{T^2} \sum_{n=-\infty}^{\infty} \left| F\left(\frac{2\pi n}{T}\right)\right|^2 \delta(\omega - n_{\omega_o}), \; \omega_o = \frac{2\pi}{T} \tag{6-3}$$

Total average power is

$$P_T = \frac{1}{2\pi} \int_{-\infty}^{\infty} \Phi_T(\omega) d\omega \tag{6-4}$$

For an aperiodic trapezoidal pulse of amplitude "A", it can be shown that

$$F(\omega) = \frac{2A}{b-a} \left[\frac{\cos a\,\omega - \cos b\,\omega}{\omega^2}\right] \tag{6-5}$$

where b — a= rise time = fall time. The above expressions were programmed and base band spectrum was evaluated from 0 to ± 30 MHz. Figures 6-3 and 6-4 show the envelope of the line spectrum on a linear scale and a logarithmic scale. The program computed a 24.07 dB S/I ratio for the case shown in Figure 6-1. This agrees with Battle's result (Reference 4) of 24.3 dB.

RESULTS FOR VARIOUS CHANNEL SEPARATIONS

For the frequency drift conditions shown in Figure 6-1, the signal-to-interference power ratio at the input to the 5 MHz bandwidth receiver was computed for various values of channel separation. TABLE 6-1 shows these values when the propagation losses are the same between the receiver and each transmitter (e.g., transmitters at same location) and when the losses are different between receiver and transmitters, based upon the configuration shown in Figure 6-2.

From TABLE 6-1 it is concluded that a condition might exist where a 6-MHz (one-channel) separation between the desired signal and an undesired signal will yield a marginal signal-to-spillover interference ratio. In particular when two transmitters are 16.5 nmi apart, the receiving antenna may be in the mainbeam of each transmitting antenna and S/I ratio will be 8.57 dB for a one channel separation. In order to maintain the S/I ratio above 20 dB, for this situation, the undesired signal must be two channels (12 MHz) away.

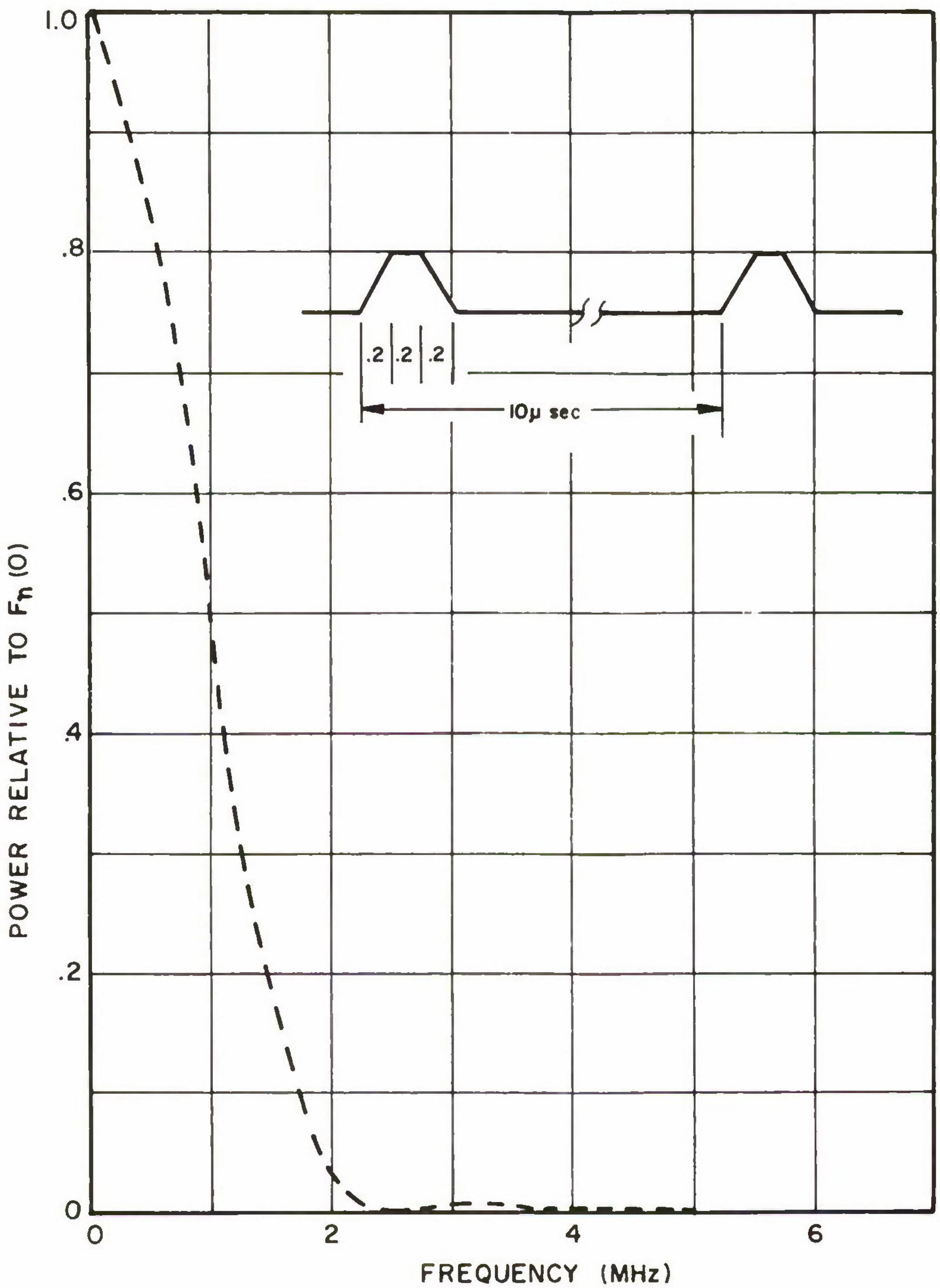

Figure 6-3. Envelope of Spectrum of Trapezoidal Waveform Shown Above

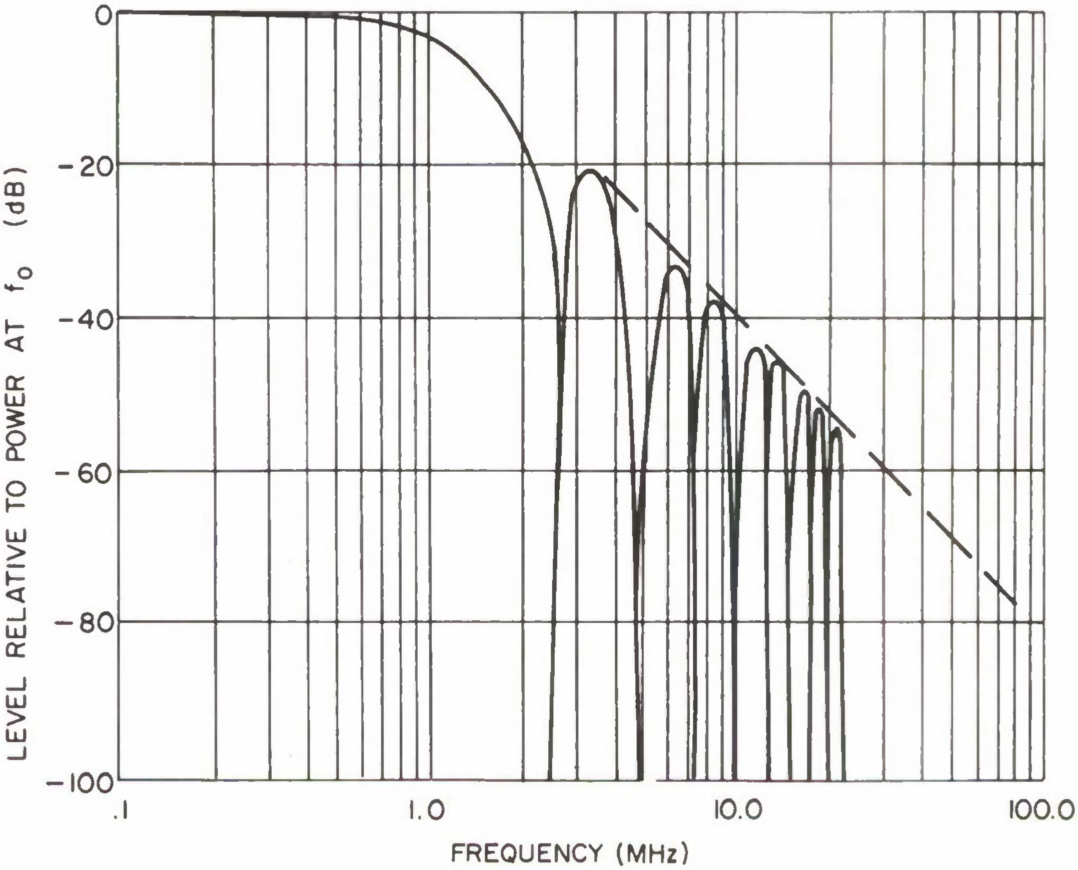

Figure 6-4. Spectrum of Time Waveform Shown in Figure 6-3

TABLE 6-1
SIGNAL TO INTERFERENCE POWER RATIOS
FOR VARIOUS VALUES OF CHANNEL SEPARATIONS

Signal-to-Adjacent Channel Power Ratio* (Transmitters at same Location)	Frequency Separation Between Center of Desired Spectrum and Adjacent Channel	Signal-to-Adjacent Channel Power Ratio (Transmitters about 16 nmi apart, Figure 6-2)
24.07 dB	6 MHz	8.57 dB
40.77 dB	12 MHz	25.27 dB
49.57 dB	18 MHz	34.07 dB
54.03	24 MHz	38.53 dB

* Distance Measuring Equipment (DME) Receiver Signal-to-Interference Retio. Signal power from DME ranging waveform; interference power from spillover due to another edjacent channel DME weveform.

CONSIDERATION OF AN ADDITIONAL CASE (NON-MAINBEAM INTERFERER ILLUMINATION OF AIRCRAFT)

In addition to the problem described above, an adjacent channel signal (from a transmitter far from the desired transmitter) may interfere with the desired receiver even when the receiving antenna is not within the mainbeam of the undesired transmitting antenna. For instance, assume that an undesired transmitter is located 20 nmi (instead of 16.5 nmi) from the desired transmitter (equal to d_1 in Figure 6-2). Due to a reduction in distance, the propagation loss between the undesired transmitter and the receiver is approximately 12 dB less than it was when the undesired transmitter was located at T_2 in Figure 6-2. If the sidelobe gain of the undesired transmitting antenna is the same as its mainbeam gain, the S/I ratio given in the right hand column of TABLE 6-1 will reduced by 12 dB. Thus, the sidelobe gain of the undesired antenna must be at least 12 dB below the mainbeam gain in order to obtain the same S/I ratios as in TABLE 6-1. If this reduction is not achieved, an adjacent signal would have to be located three channels from the desired signal.

CONSIDERATION OF RAIN ATTENUATION

Presence of rain in the situation depicted in Figure 6-2 will alter the results shown in TABLE 6-1. Propagation loss for this condition may be represented as 37 + 20 log F (MHz) + 20 log d (mi) + K_r d (mi), where K_r is an average rain attenuation factor in dB per nautical mile. Equation 6-1 then becomes

$$\text{Loss Difference} = 20 \log \frac{121{,}750}{20{,}500} + K_r \left(\frac{121{,}750-20{,}500}{5{,}280}\right)$$

$$= 15.45 + 19.2\, K_r \quad \text{dB} \qquad (6\text{-}6)$$

The factor K_r is generally empirically determined as a function of rainfall rate and propagating frequency. The values computed by methods of reference 6 for a rainfall rate of 100 millimeters per hour are K_r = 0.6, 8.0 and 24 dB per mile for frequencies of 5, 9 and 15 GHz respectively. The loss difference (LD) for the above case for the three frequencies are then:

LD = 27.0 dB, F = 5 GHz

LD = 169 dB, F = 9 GHz

LD = 476 dB, F= 15 GHz

TABLE 6-2 was developed using these loss difference values in lieu of the 15.45 dB used to develop TABLE 6-1.

TABLE 6-2
SIGNAL-TO-INTERFERENCE POWER RATIO FOR VARIOUS VALUES OF CHANNEL SEPARATION AND 100 MM/HR. RAINFALL

Frequency Separation Between Center of Desired Spectrum and Adjacent Channel (MHz)	Signal-to-Adjacent Channel Power Ratio (Transmitters about 16 nmi apart, Figure 6-2)		
	For F = 5 GHz (dB)	For F = 9 GHz (dB)	For F = 15 GHz (dB)
6	– 3.0	–145	–452
12	+13.8	–129	–436
18	+22.6	–120	–427
24	+27.0	–115	–422

The large negative values of S/I at 9 and 15 GHz which reflect the effects of rain absorption clearly indicate the problems at these frequencies. No attempt was made to establish channel separations which would accomodate this situation.

APPENDIX I

ADDITIONAL RESULTS OF ENVIRONMENTAL STUDY

This appendix contains graphs and tables depicting the primary environments seen from nine major airports. Similar data for a tenth airport is shown in SECTION 3. Including a detailed discussion of the graphs and tables. The nine airports covered here are:

1. Atlanta Airport, Altanta, Ga.
2. Logan International, Boston, Mass.
3. O'Hare International, Chicago, Ill.
4. Dallas Love Field, Dallas, Tex.
5. Dulles International, Washington, D. C.
6. Los Angeles International, Los Angeles, Calif.
7. Miami International, Miami, Fla.
8. New Orleans International, New Orleans, La.
9. Panama City, Bay Co. Airport, Fla.

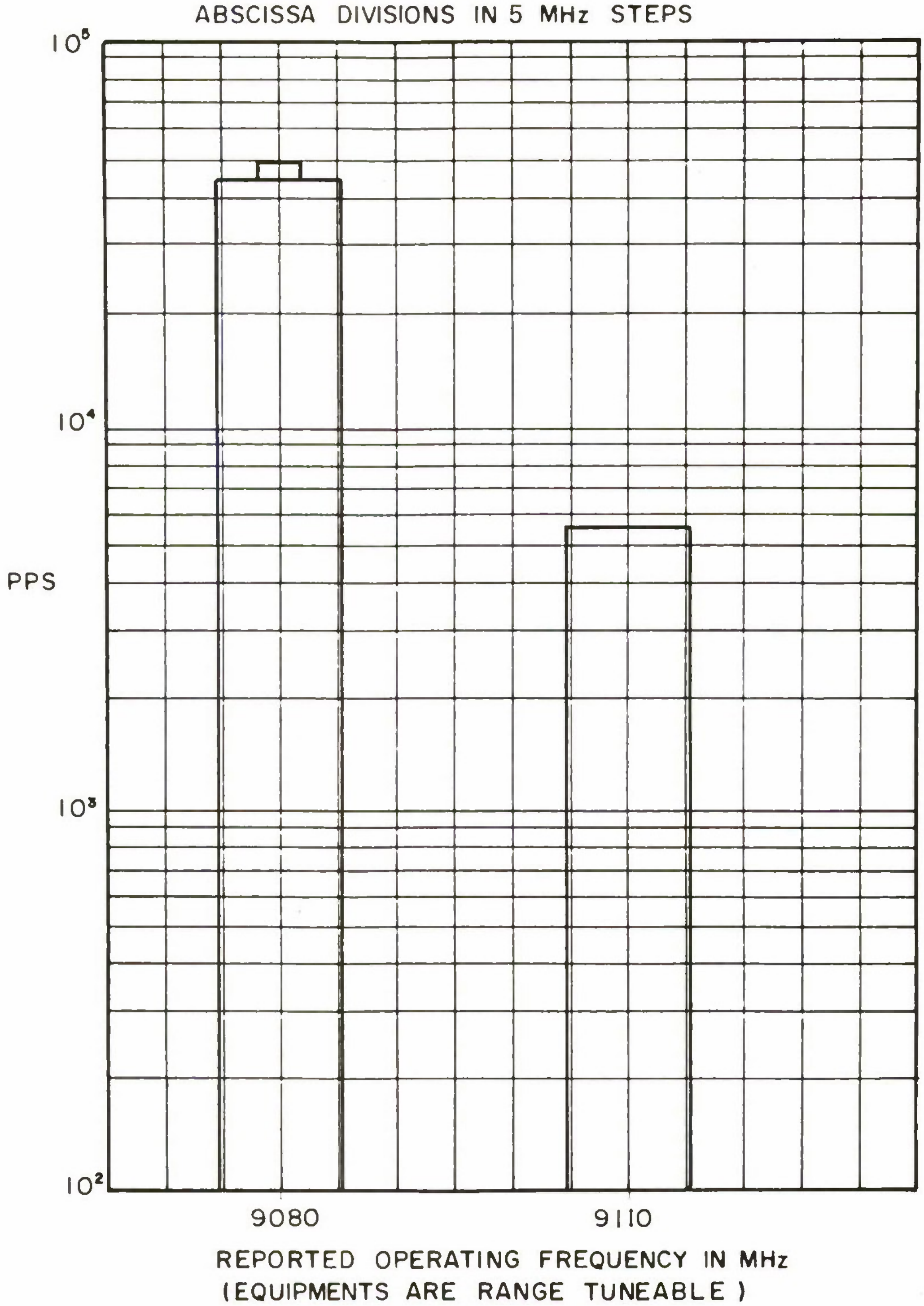

Figure I-1. Histogram of Cumulative Pulse Rate of Environmental Transmitters at Atlanta, Category A, 0.12 – 0.2 μs pulses

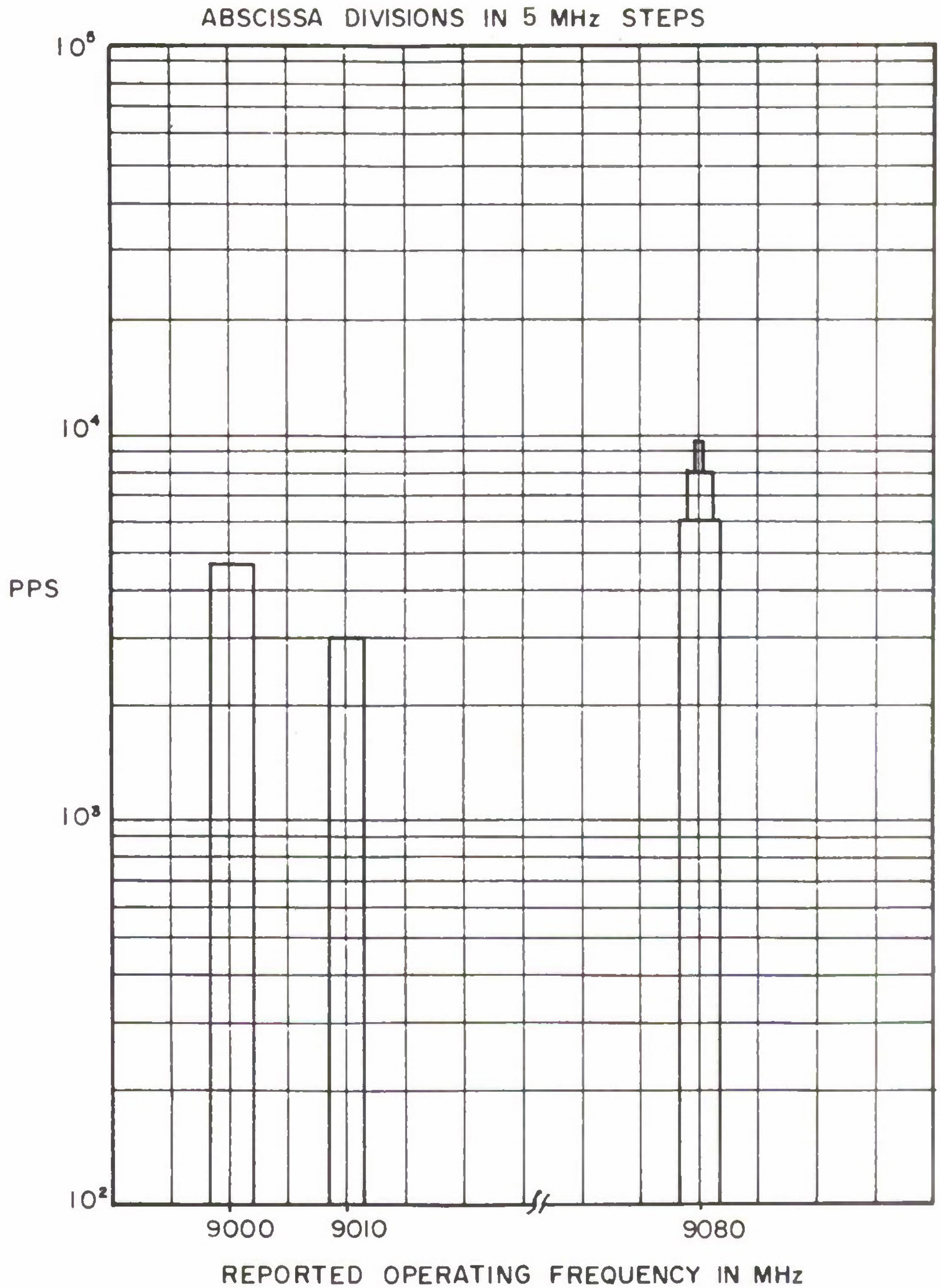

Figure I-2. Histogram of Cumulative Pulse Rate of Environmental Transmitters at Atlanta, Category B, 0.5 – 0.8 μs pulses

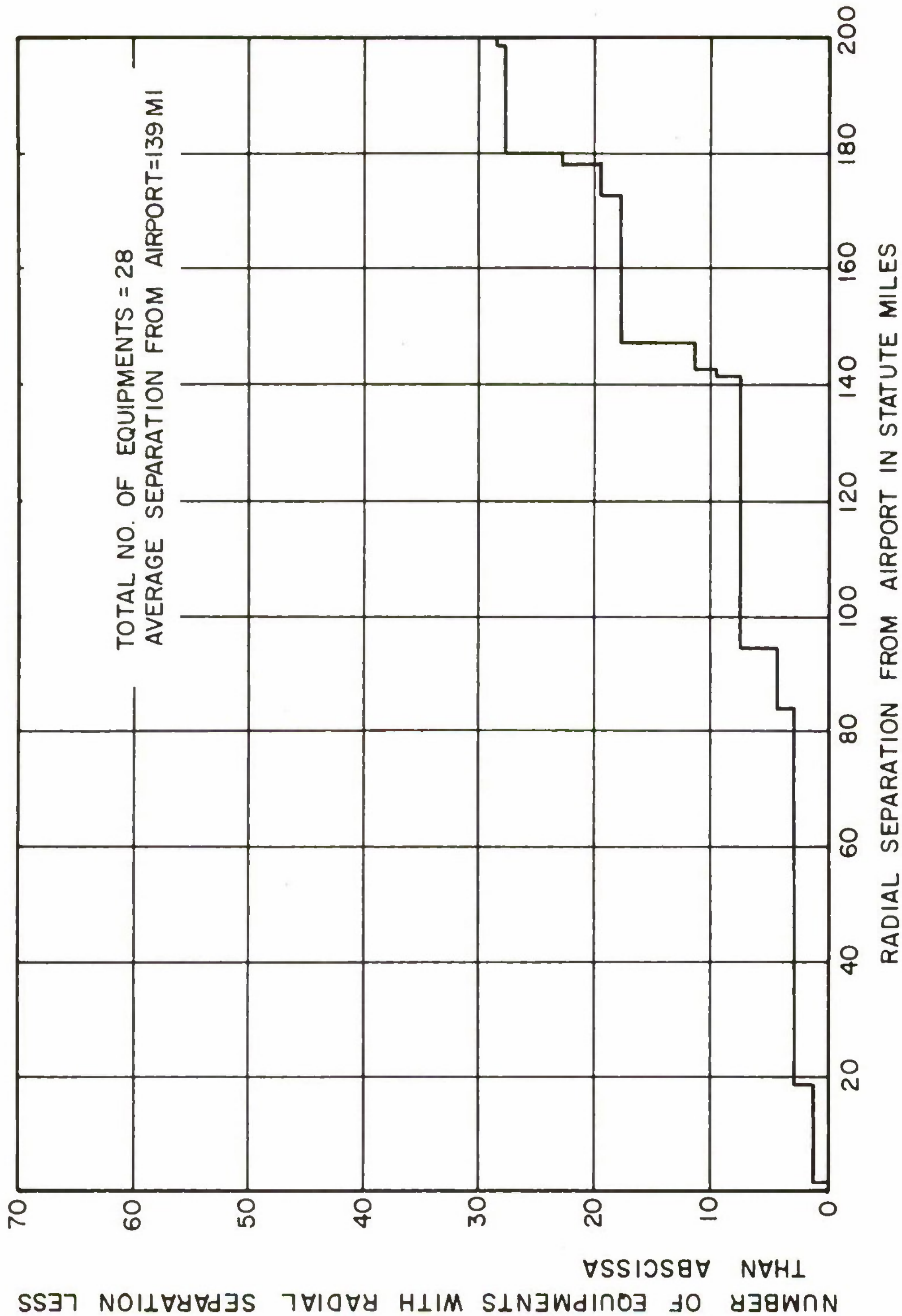

Figure I-3. Distribution of Emitters Within 200 Miles of Atlanta Airport

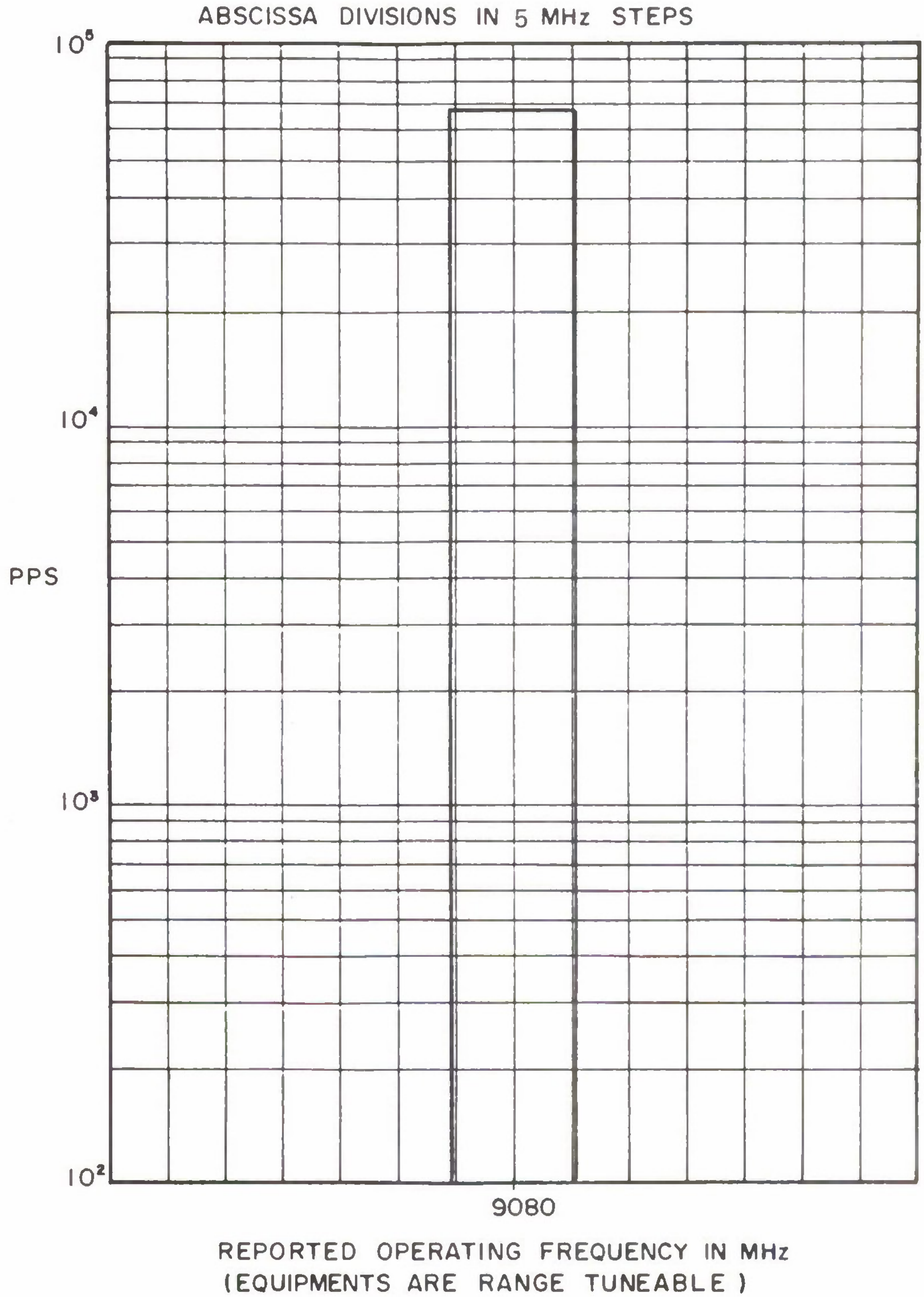

Figure I-4. Histogram of Cumulative Pulse Rate of Environmental Transmitters at Boston, Category A, 0.12 – 0.2 μs pulses

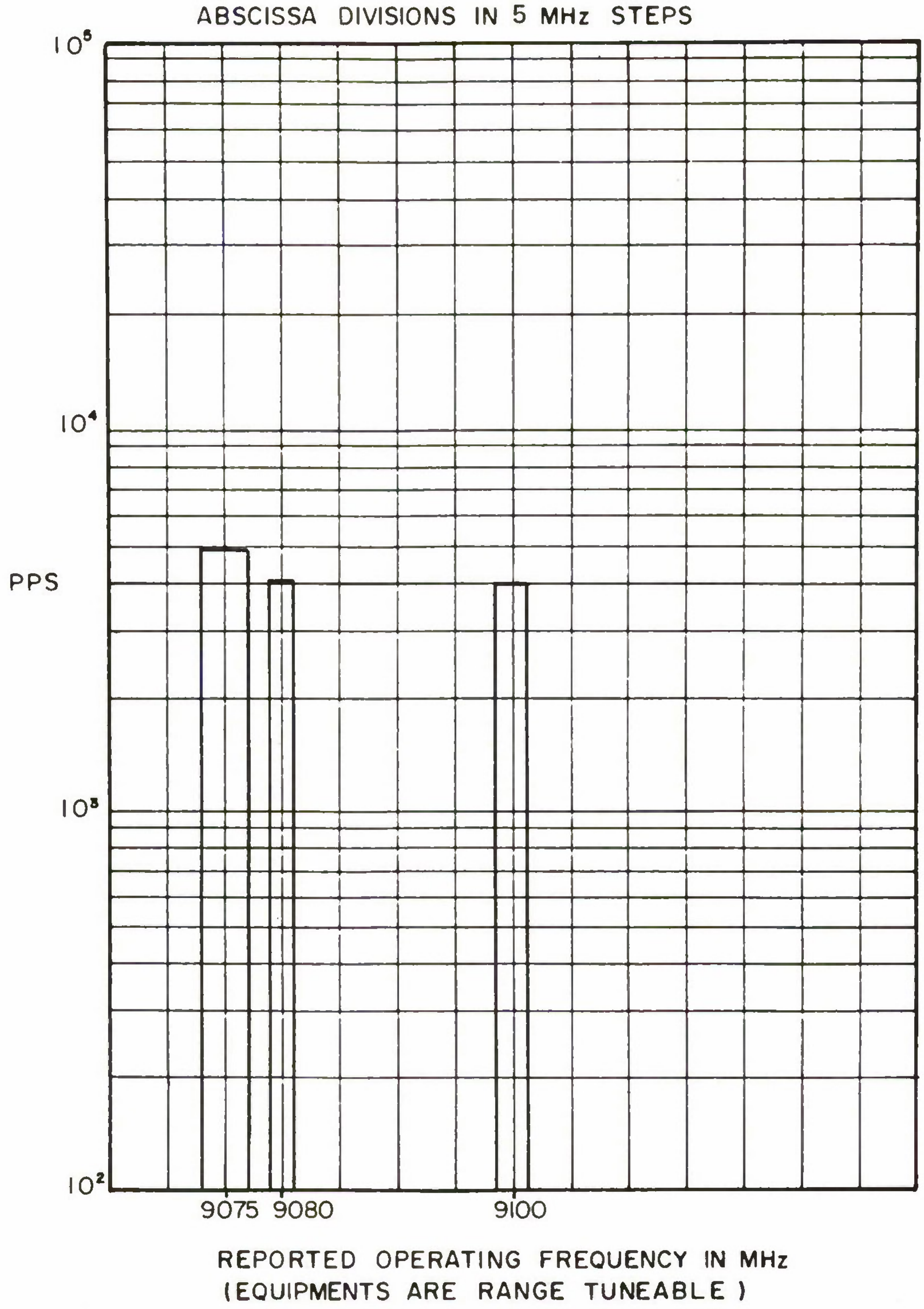

Figure I-5. Histogram of Cumulative Pulse Rate of Environmental Transmitters at Boston, Category B, 0.5 — 0.8 μs pulses

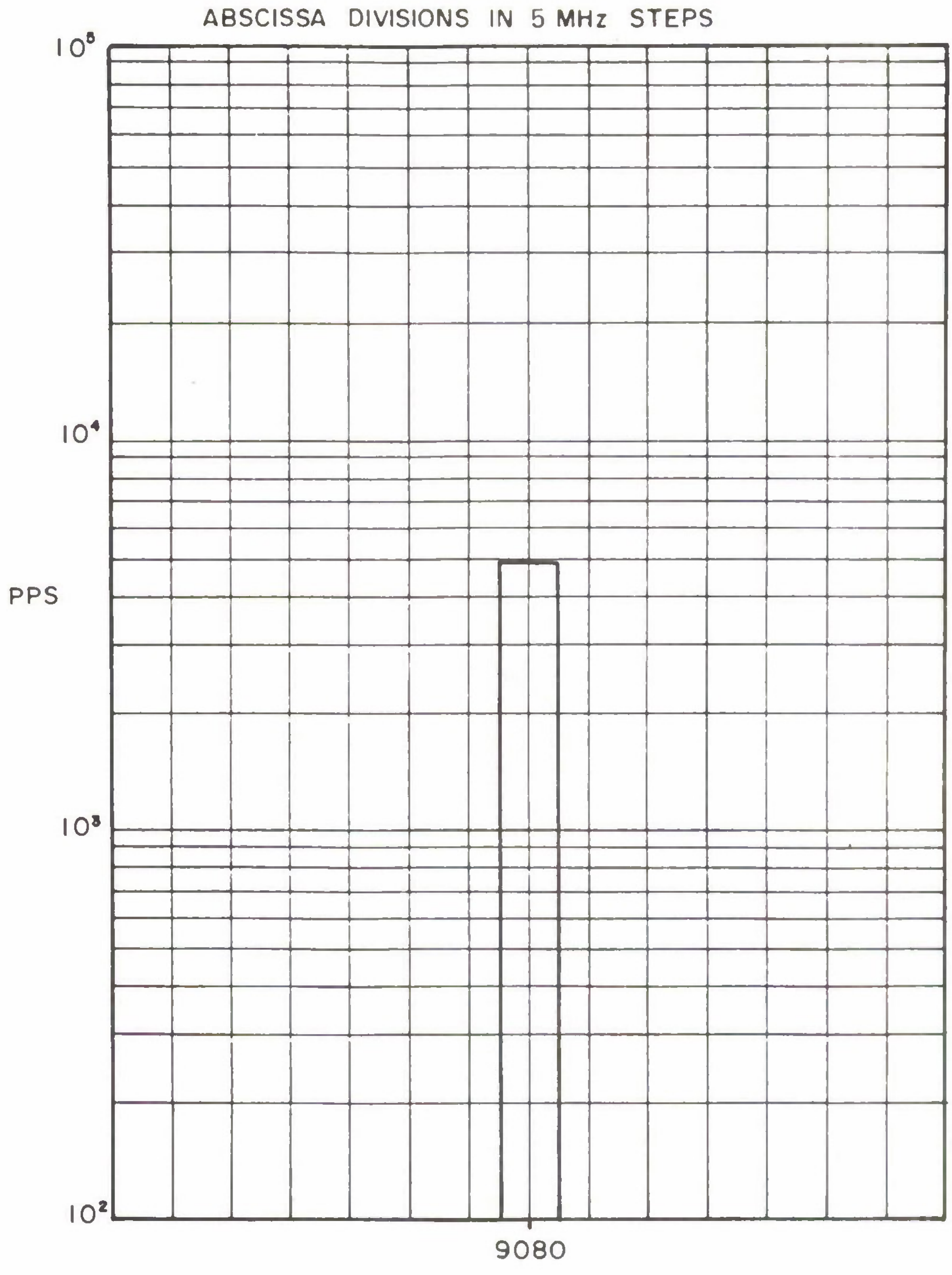

Figure I-6. Histogram of Cumulative Pulse Rate of Environmental Transmitters at Boston, Category C, 0.24 – 0.25 μs pulses

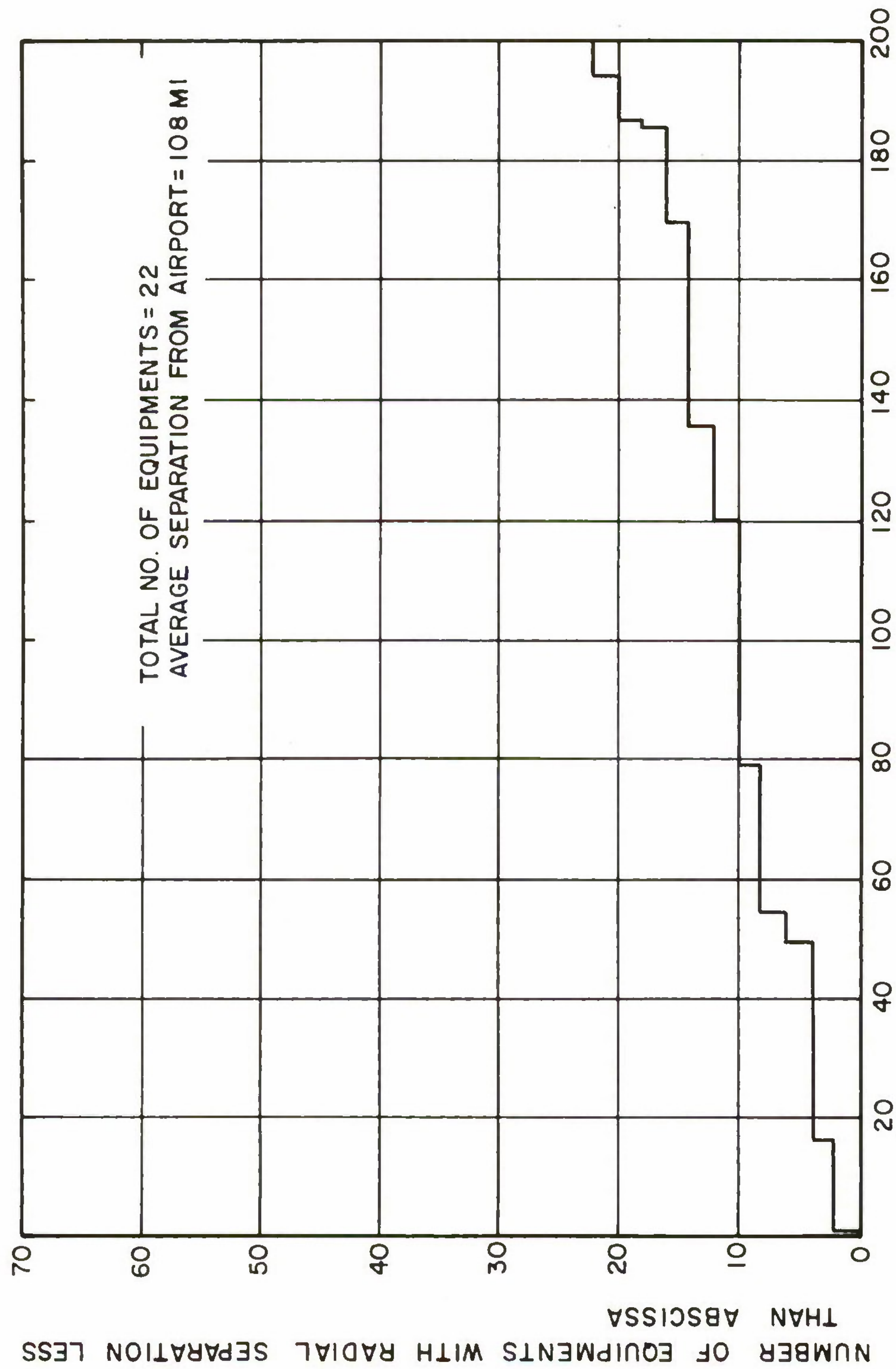

Figure I-7. Distribution of Emitters within 200 Miles of Boston's Logan International Airport

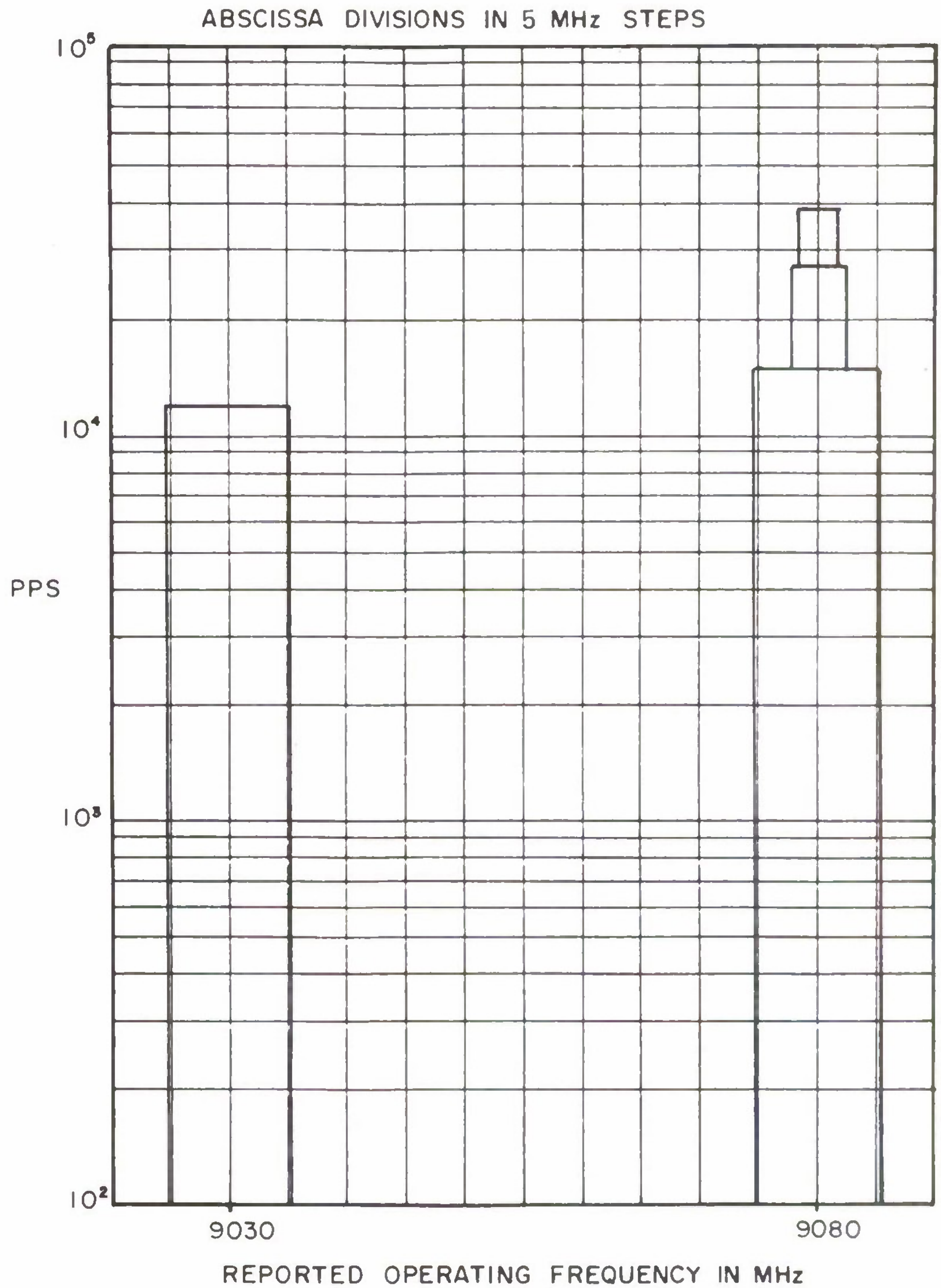

Figure I-8. Histogram of Cumulative Pulse Rate of Environmental Transmitters at Chicago, Category A, 0.12 – 0.2 μs pulses

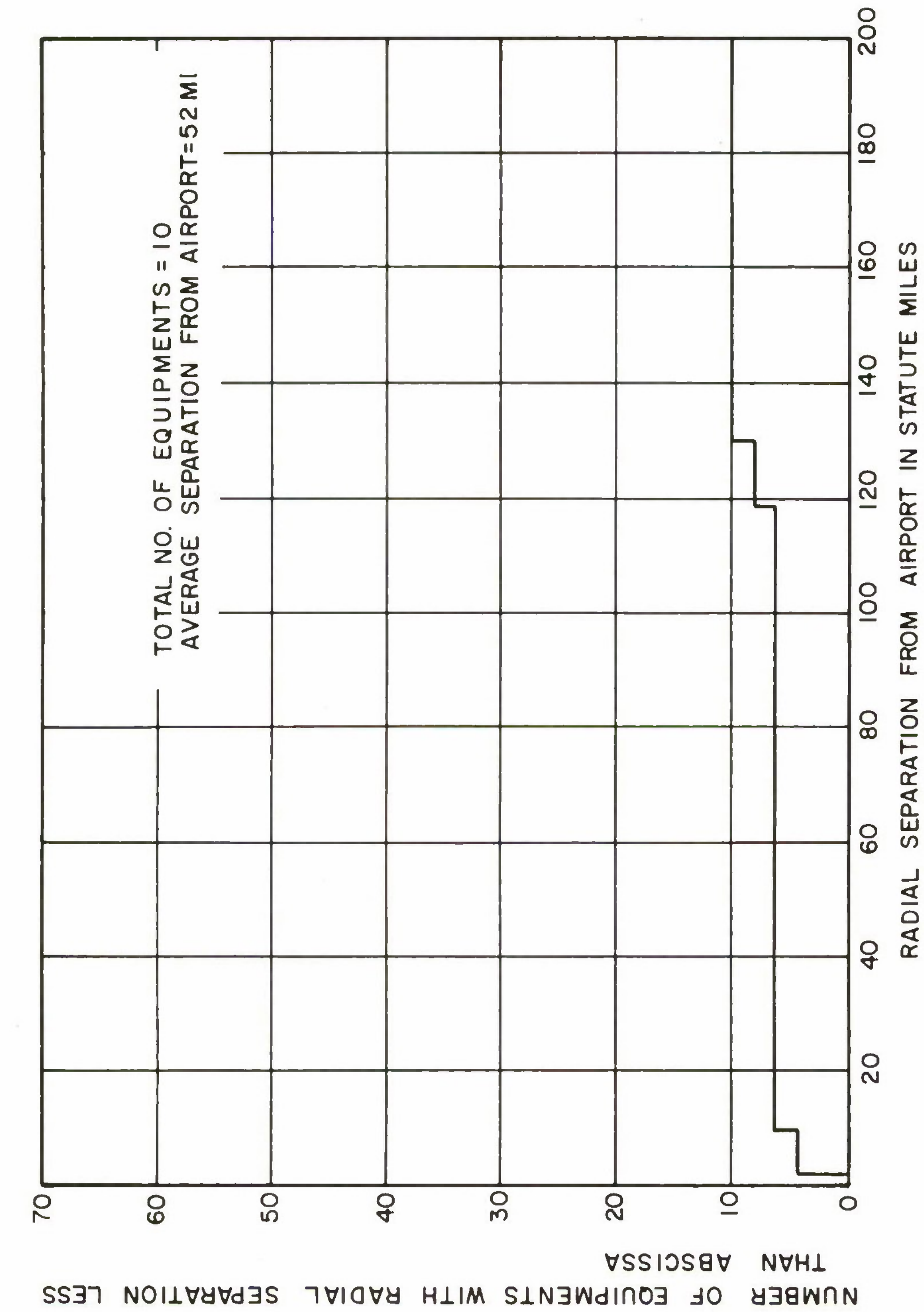

Figure I-9. Distribution of Emitters within 200 Miles of Chicago's O'Hare International Airport

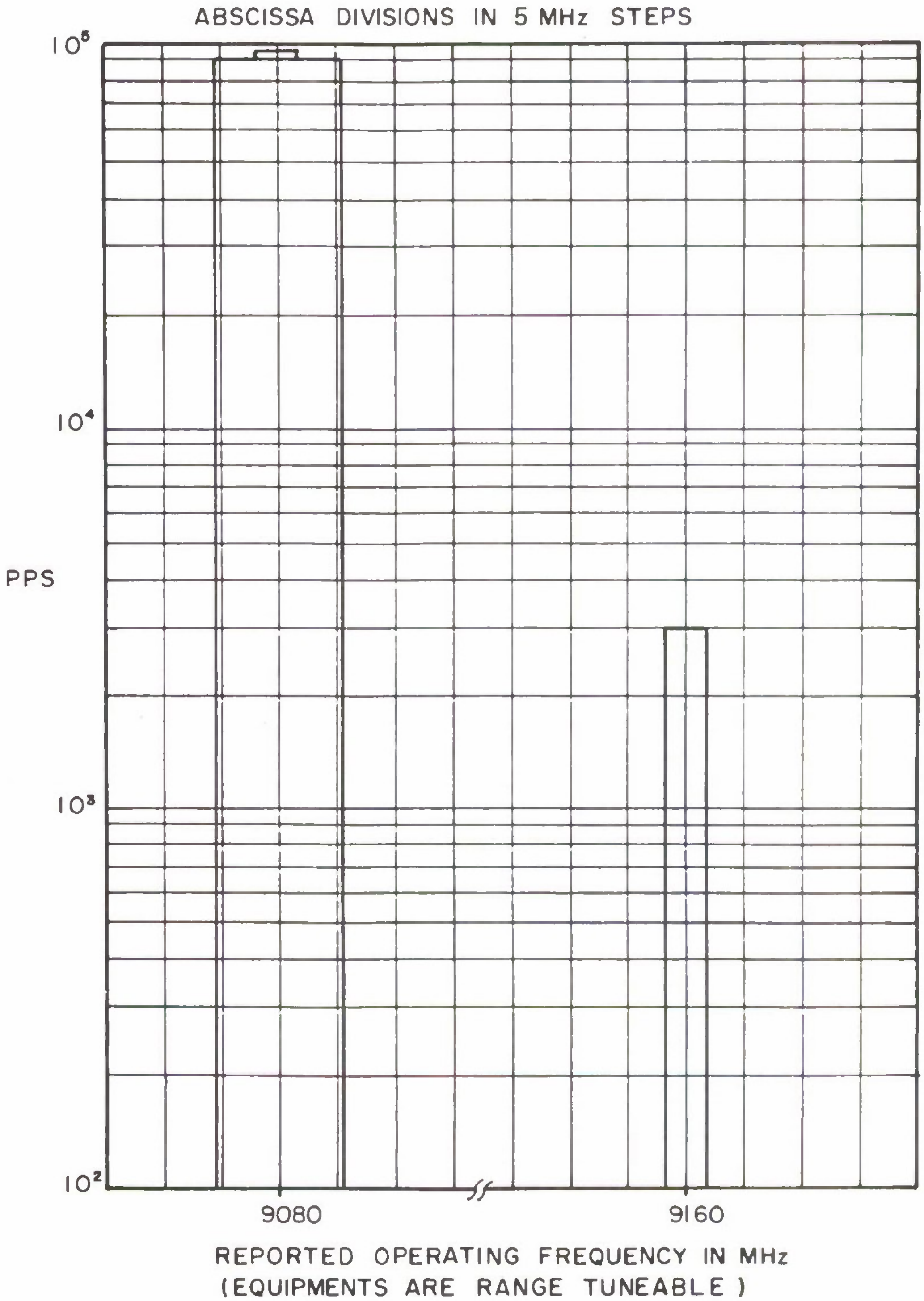

Figure I-10. Histogram of Cumulative Pulse Rate of Environmental Transmitters at Dallas, Category A, 0.12 – 0.2 μs pulses

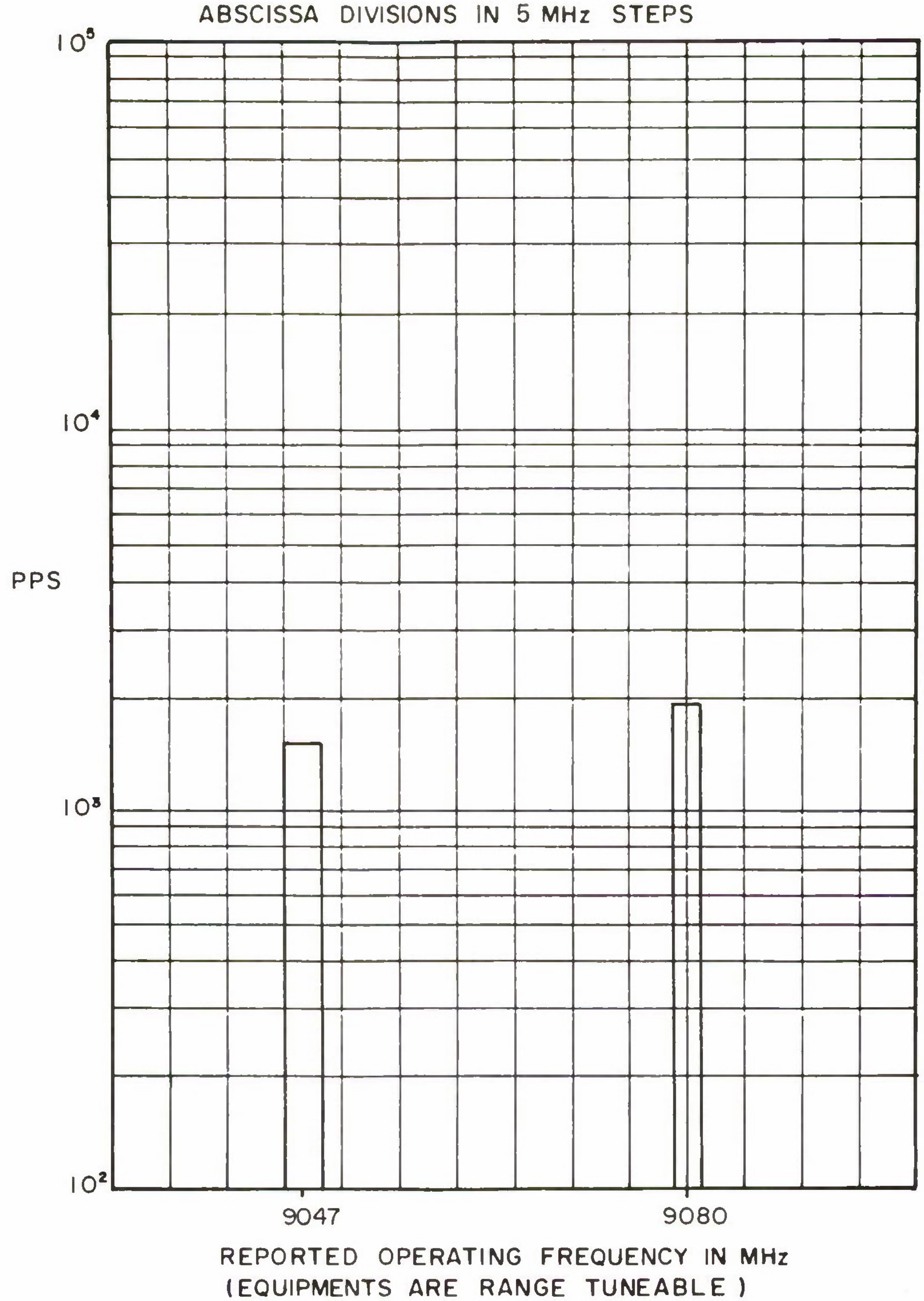

Figure I-11. Histogram of Cumulative Pulse Rate of Environmental Transmitters at Dallas, Category B, 0.5 — 0.8 μs pulses

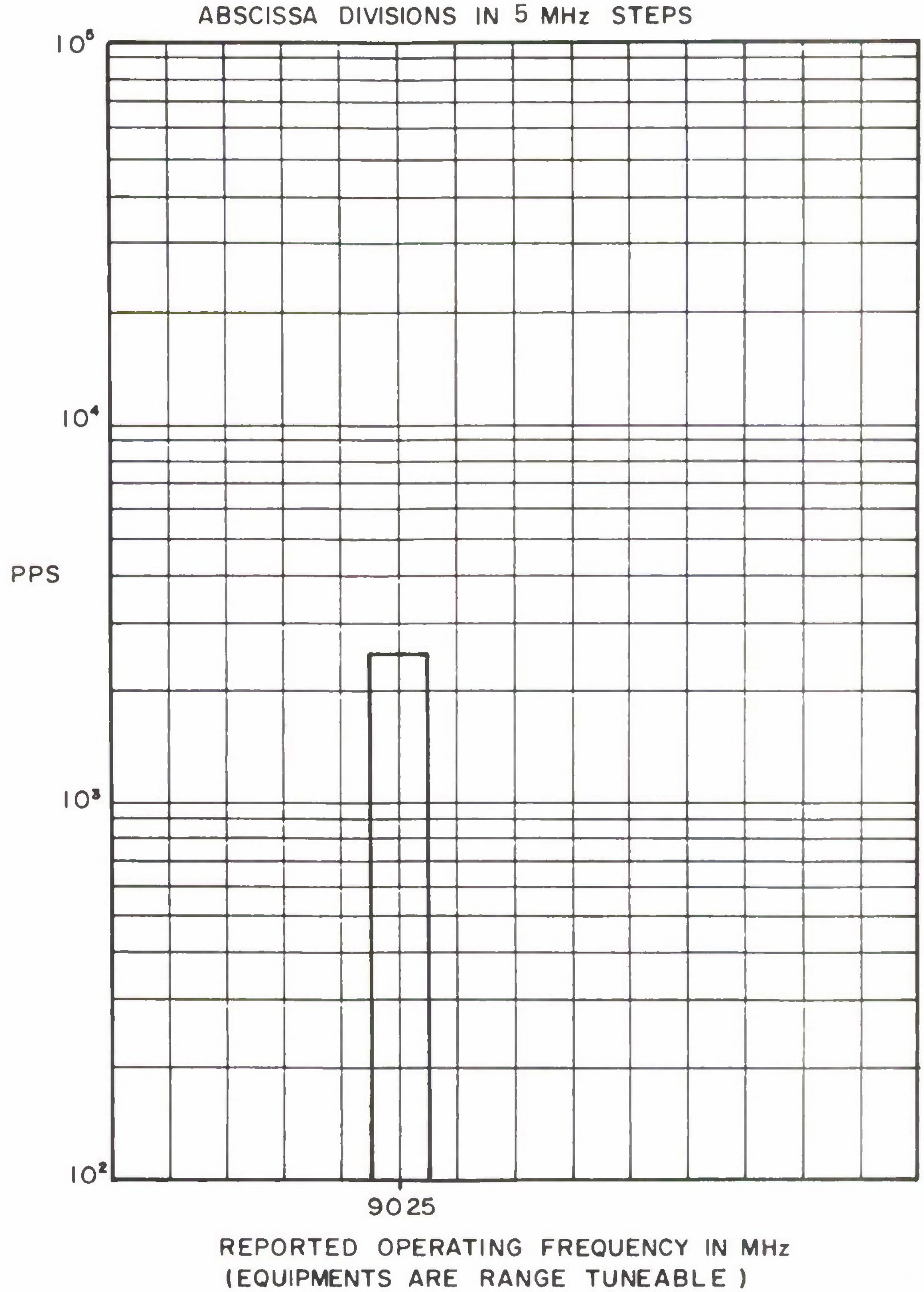

Figure I-12. Histogram of Cumulative Pulse Rate of Environmental Transmitters at Dallas, Category C, 0.24 – 0.25 μs pulses

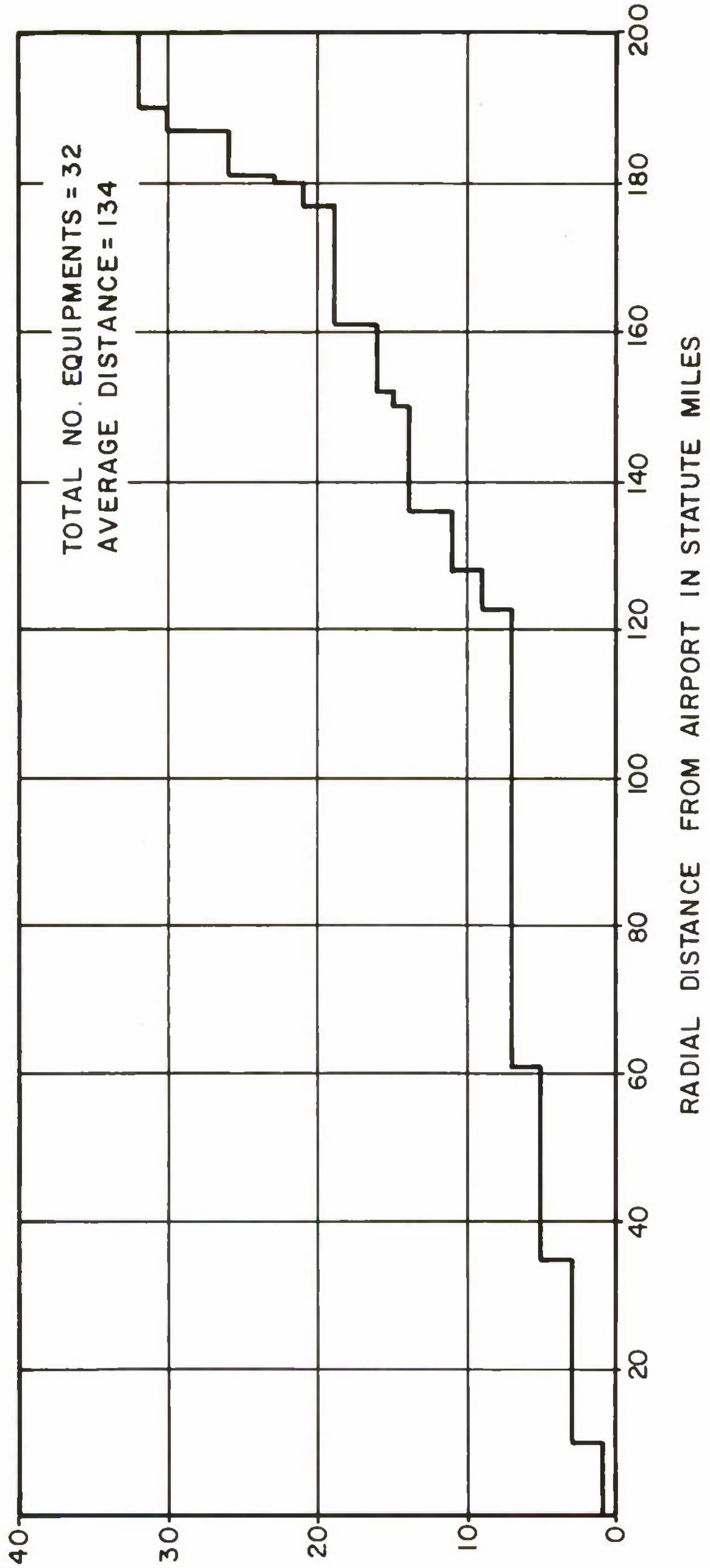

Figure I-13. Distribution of Emitters Within 200 Miles of Dallas Love Field.

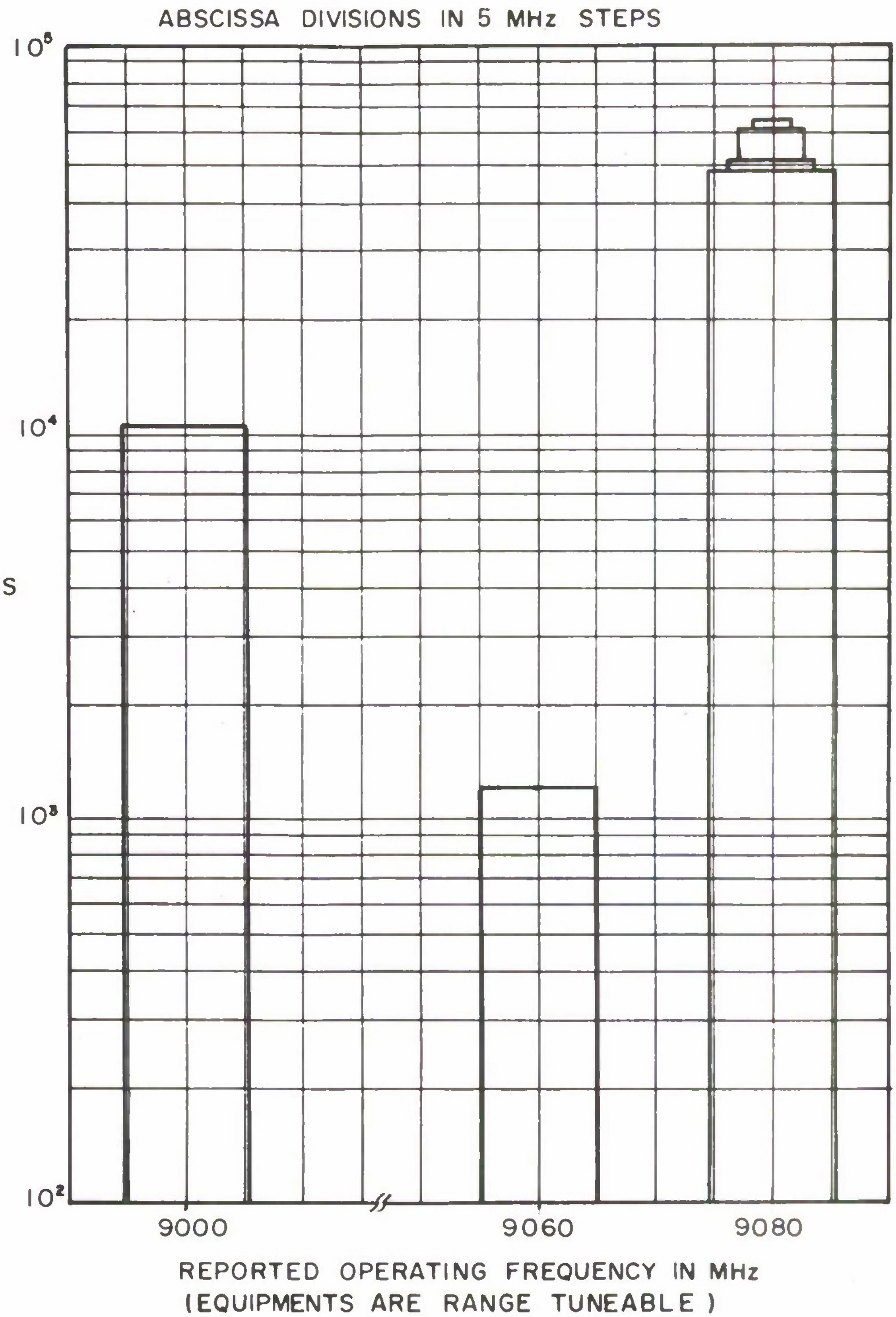

Figure I-14. Histogram of Cumulative Pusle Rate of Environmental Transmitters at Dulles, Category A, 0.12 – 0.2 μs pulses

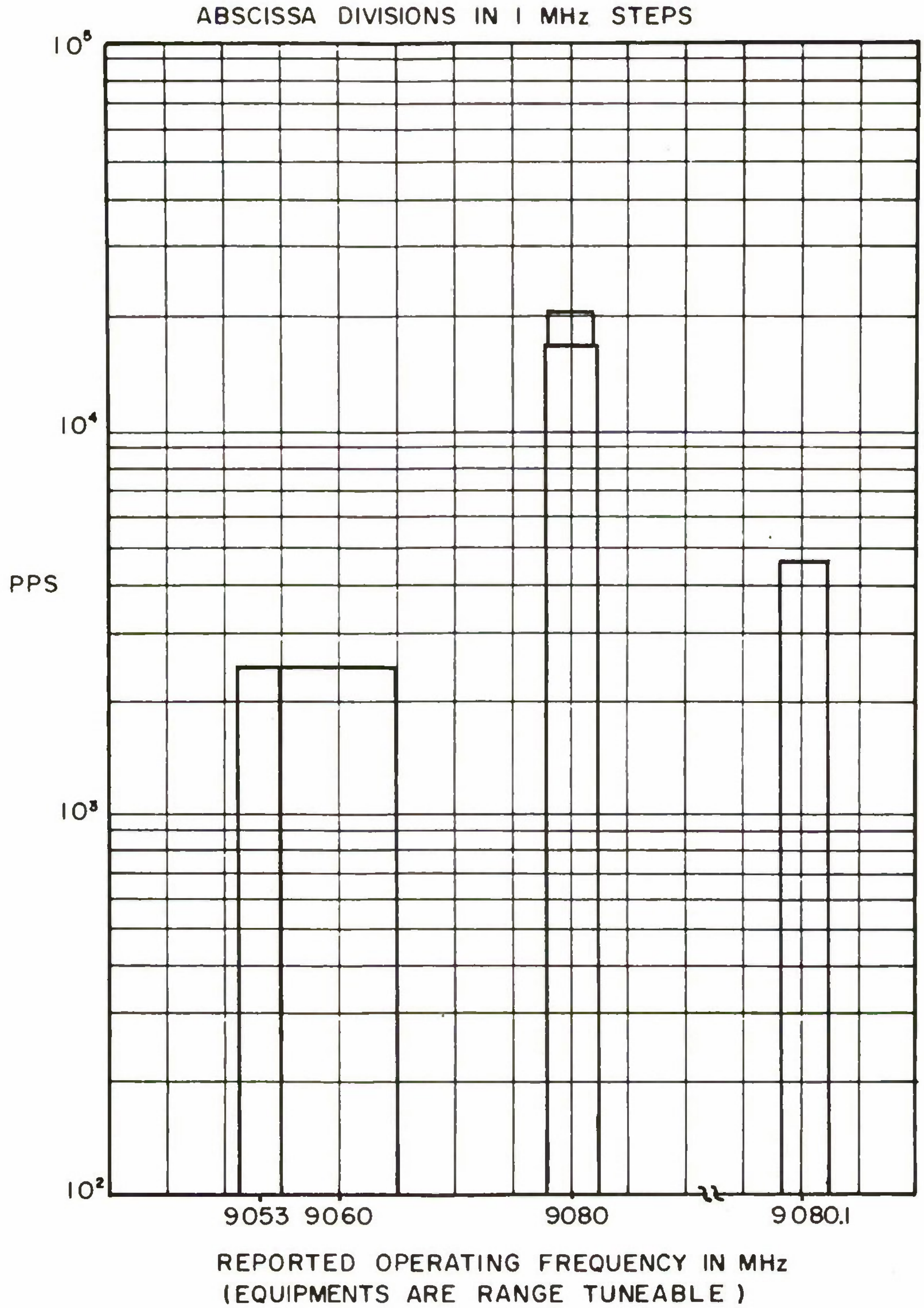

Figure I-15. Histogram of Cumulative Pulse Rate of Environmental Transmitters at Dulles, Category B, 0.5 – 0.8 μs pulses

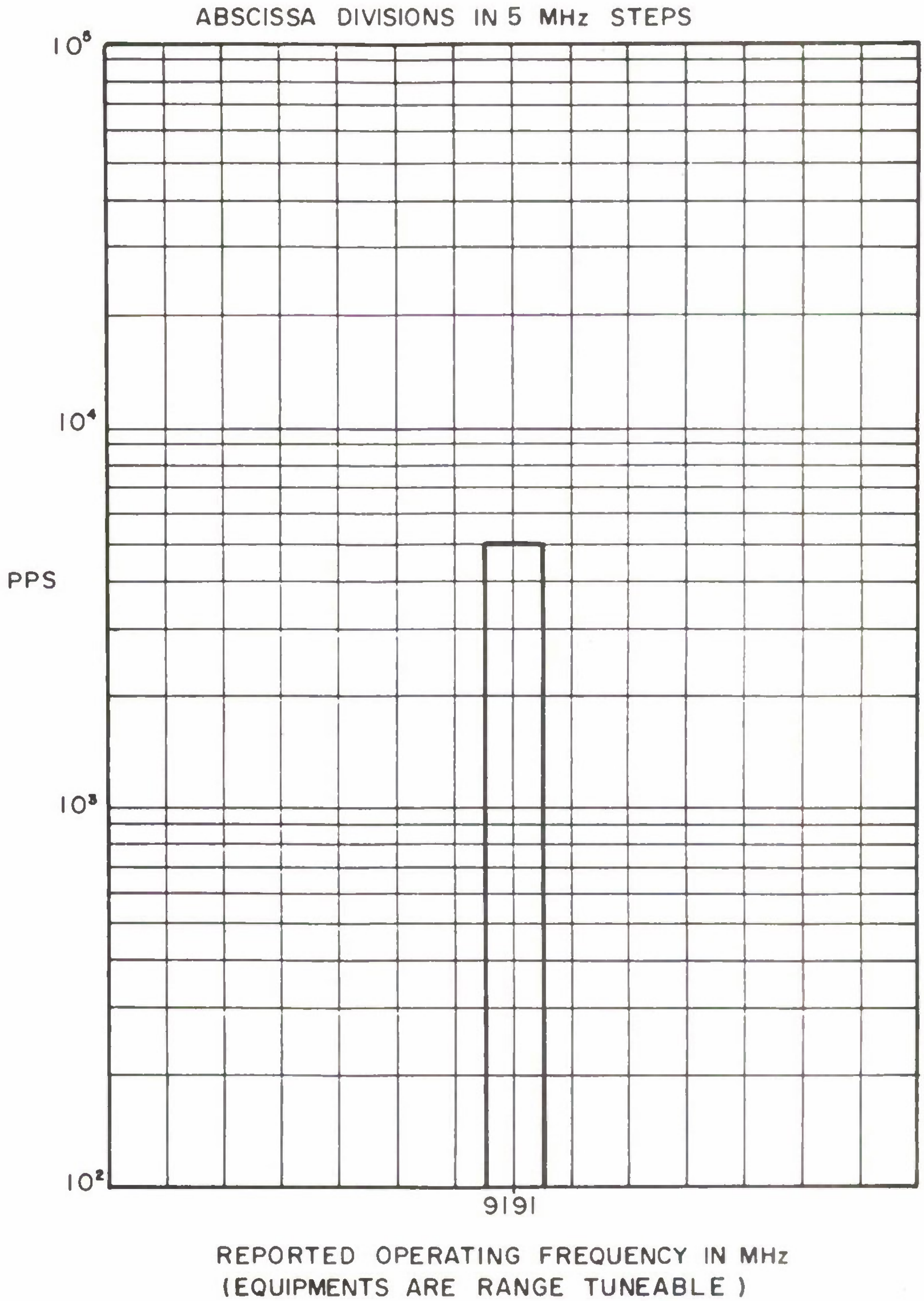

Figure I-16. Histogram of Cumulative Pulse Rate of Environmental Transmitters at Dulles, Category C, 0.24 – 0.25 μs pulses

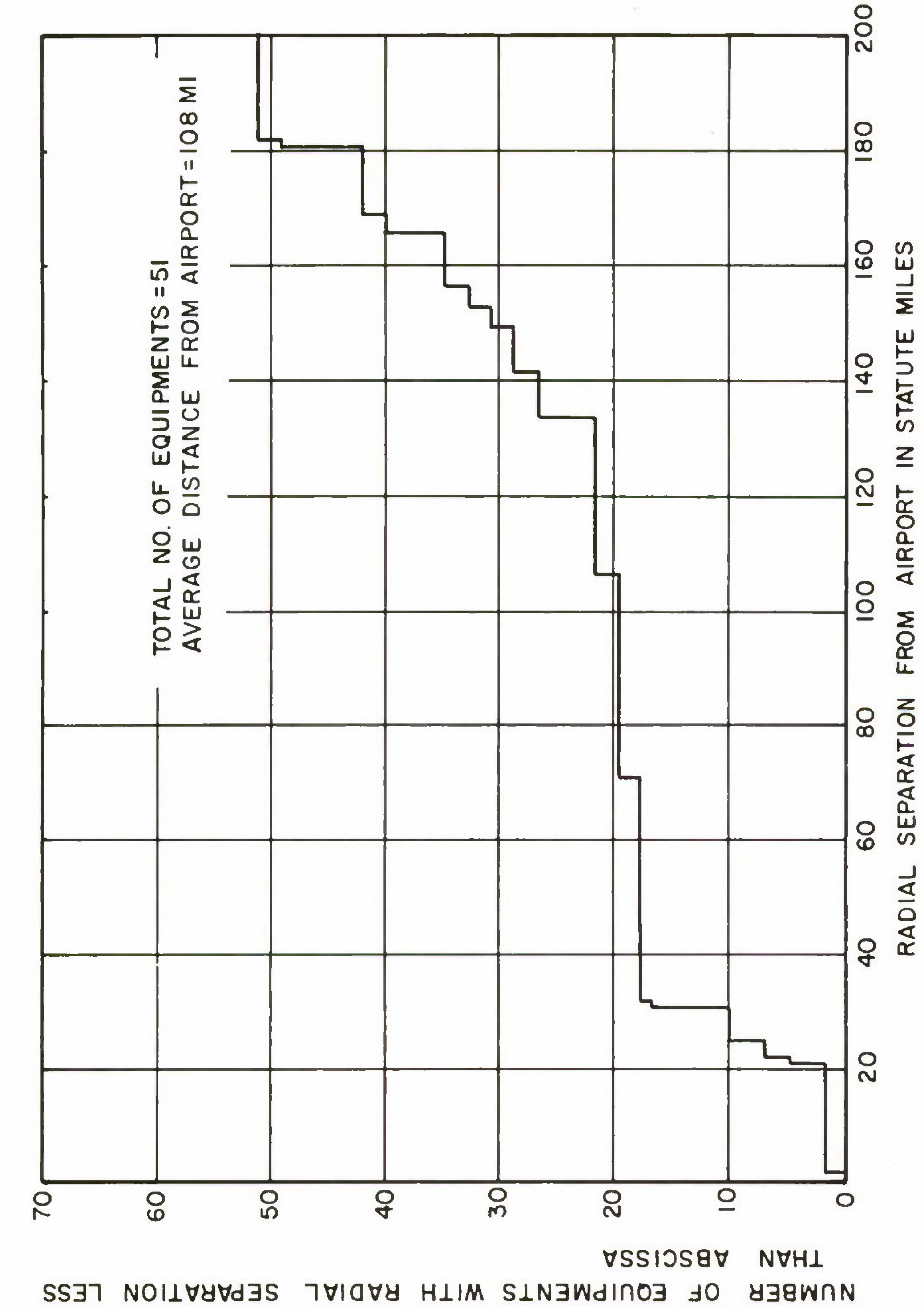

Figure I-17. Distribution of Emitters within 200 Miles of Dulles International Airport

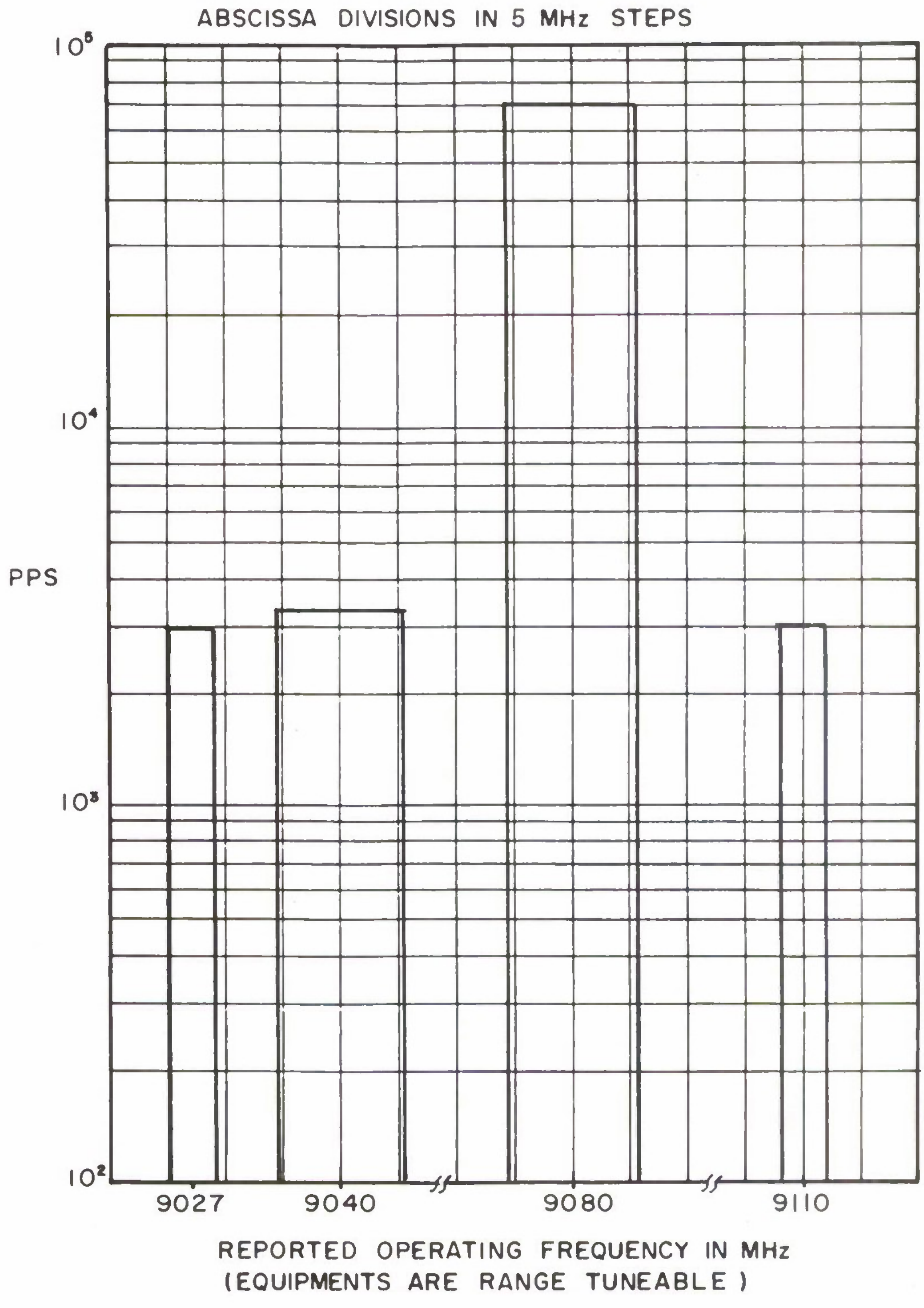

Figure I-18. Histogram of Cumulative Pulse Rate of Environmental Transmitters at Los Angeles, Category A, 0.12 – 0.2 μs pulses

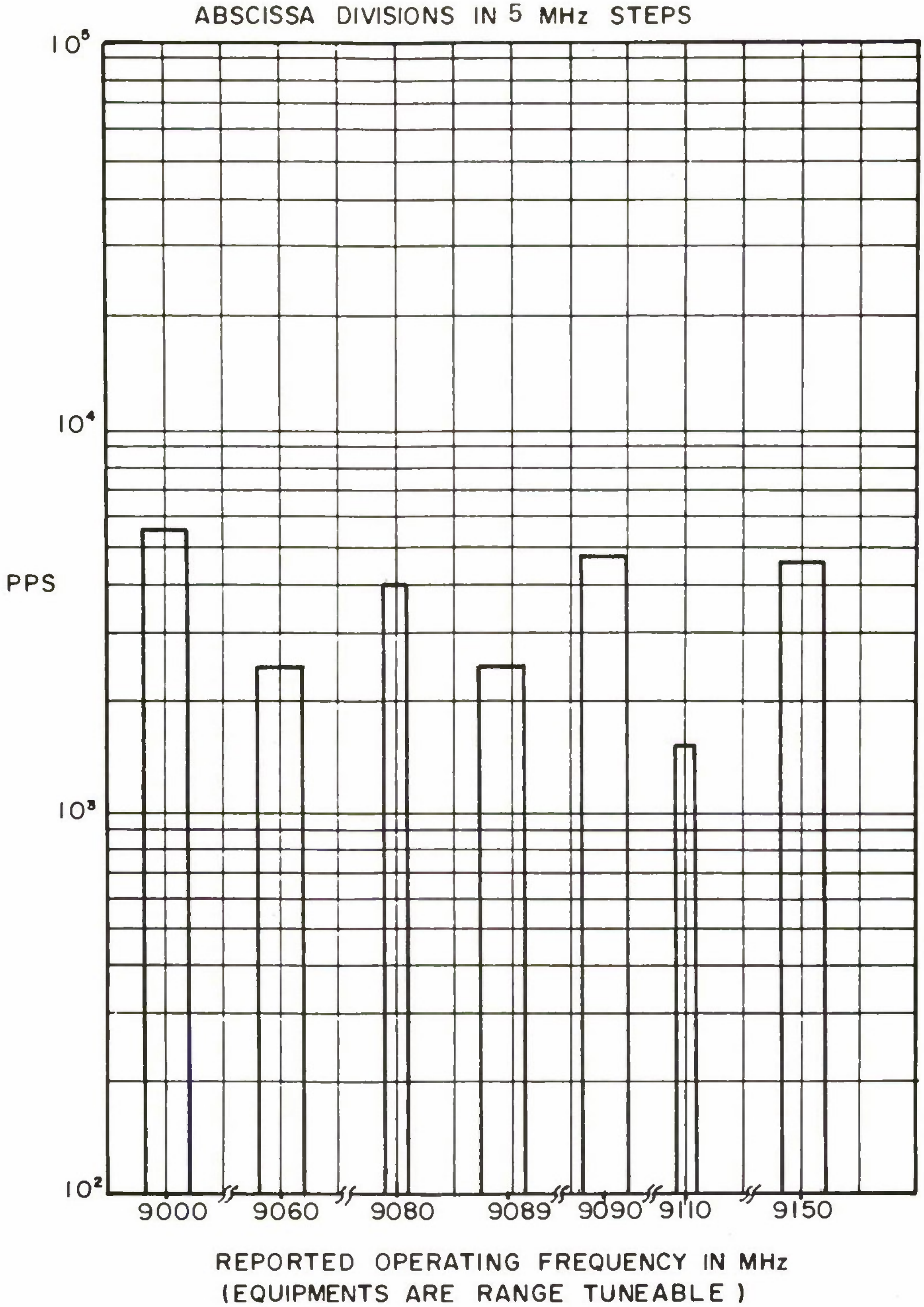

Figure I-19. Histogram of Cumulative Pulse Rate of Environmental Transmitters at Los Angeles, Category B, 0.5 – 0.8 μs pulses

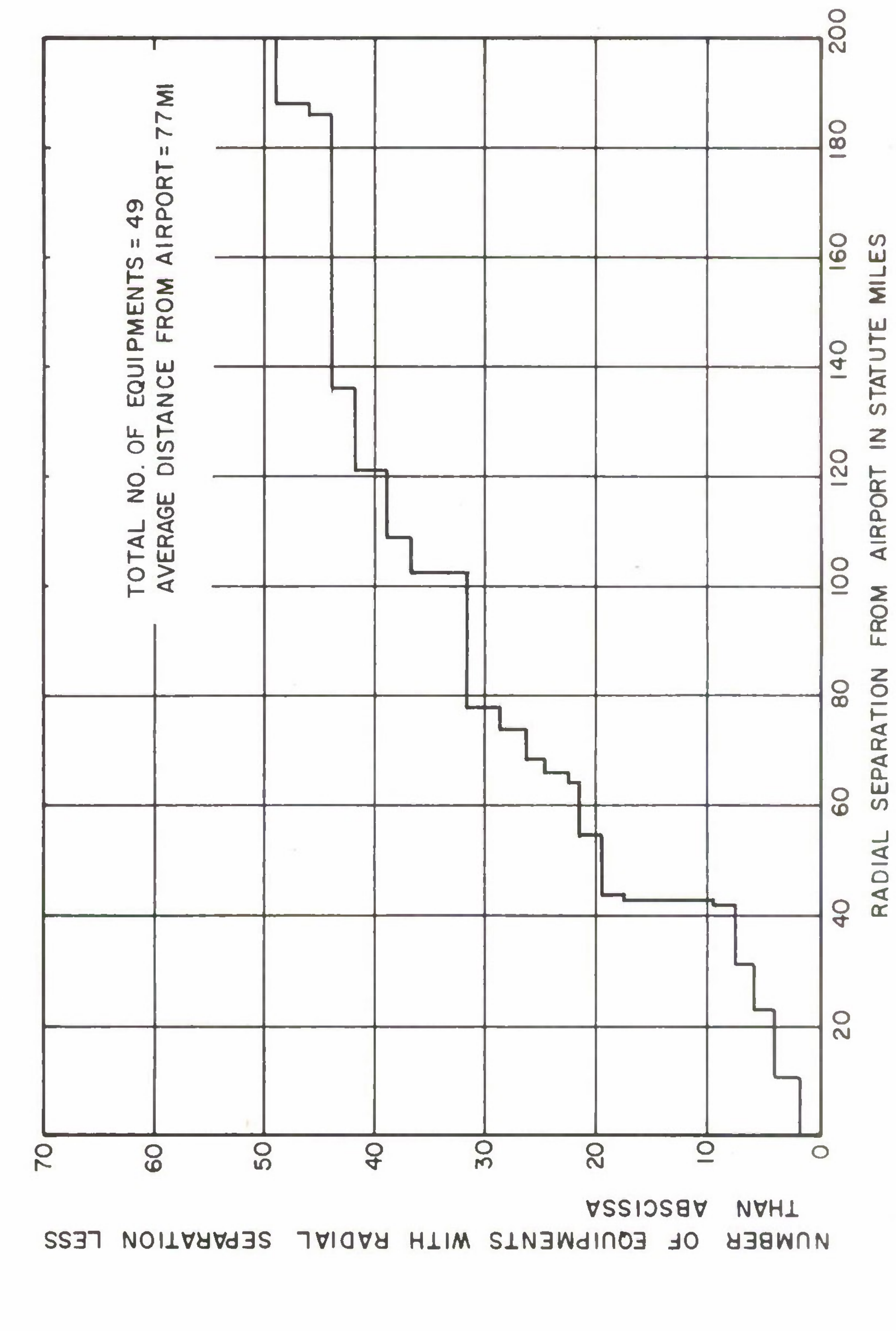

Figure I-20. Distribution of Emitters within 200 Miles of Los Angeles International Airport

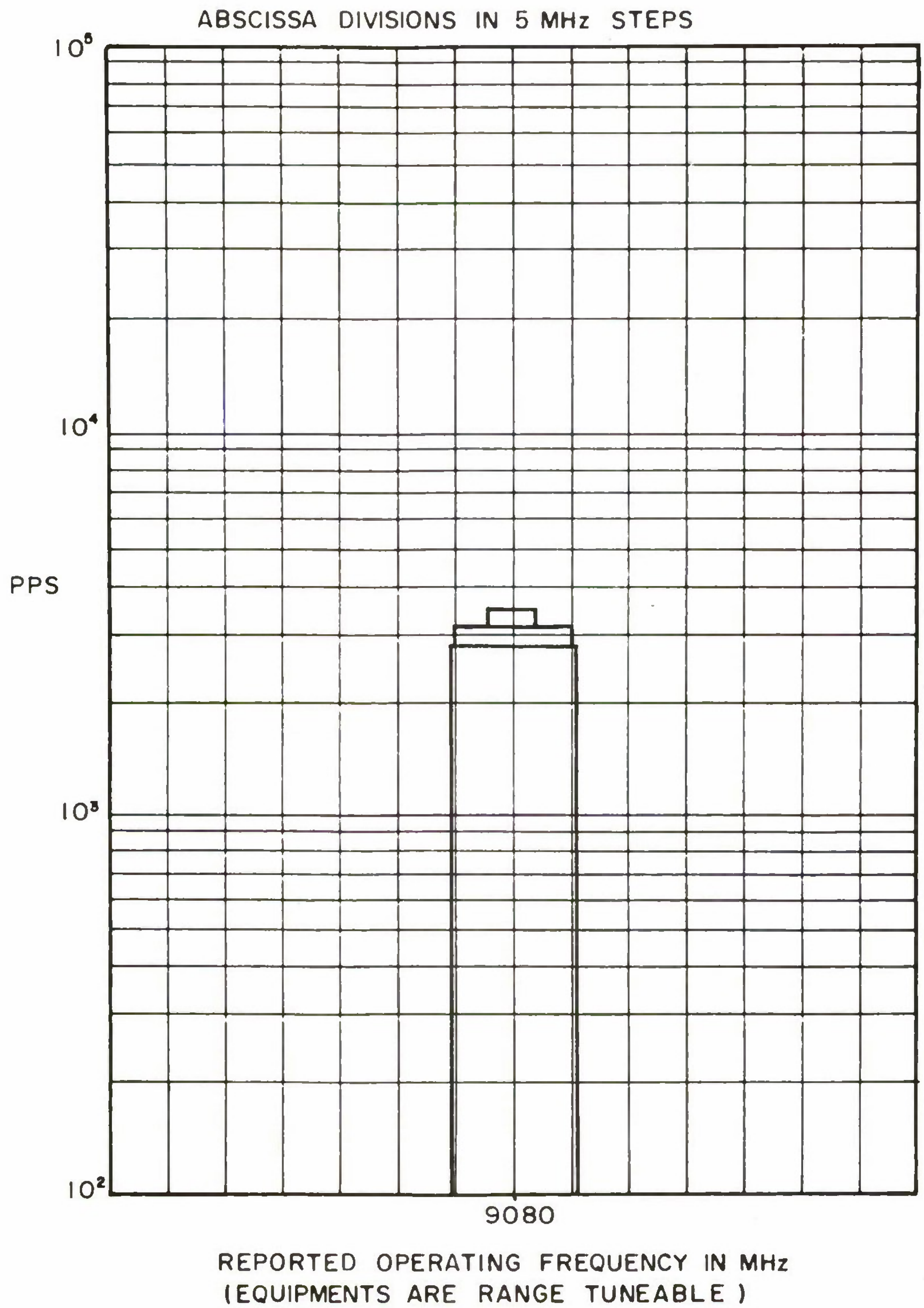

Figure I-21. Histogram of Cumulative Pulse Rate of Environmental Transmitters at Miami, Category A, 0.12 – 0.2 μs pulses

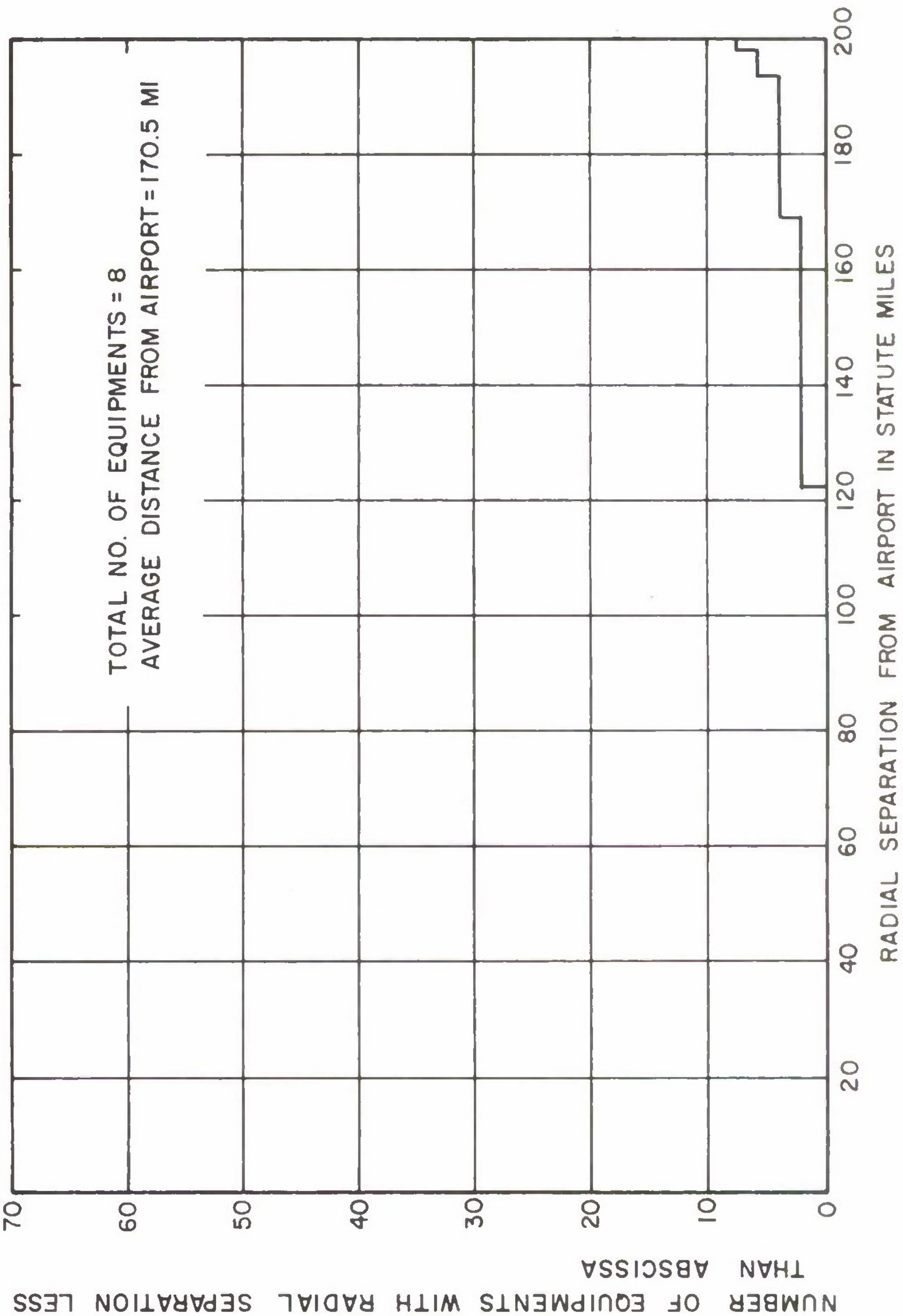

Figure I-22. Distribution of Emitters within 200 Miles of Miami International Airport

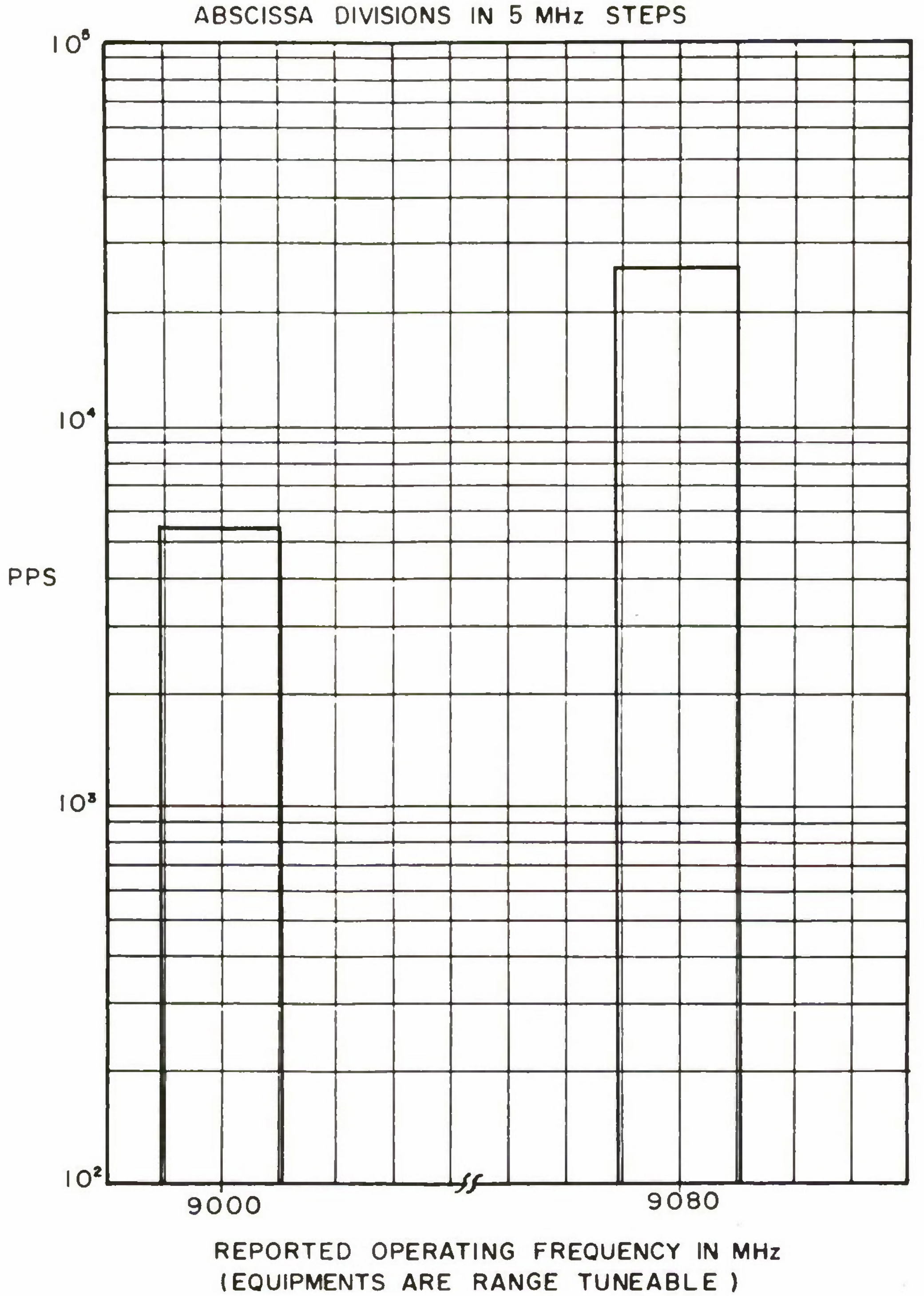

Figure I-23. Histogram of Cumulative Pulse Rate of Environmental Transmitters at New Orleans, Category A, 0.12 – 0.2 μs pulses

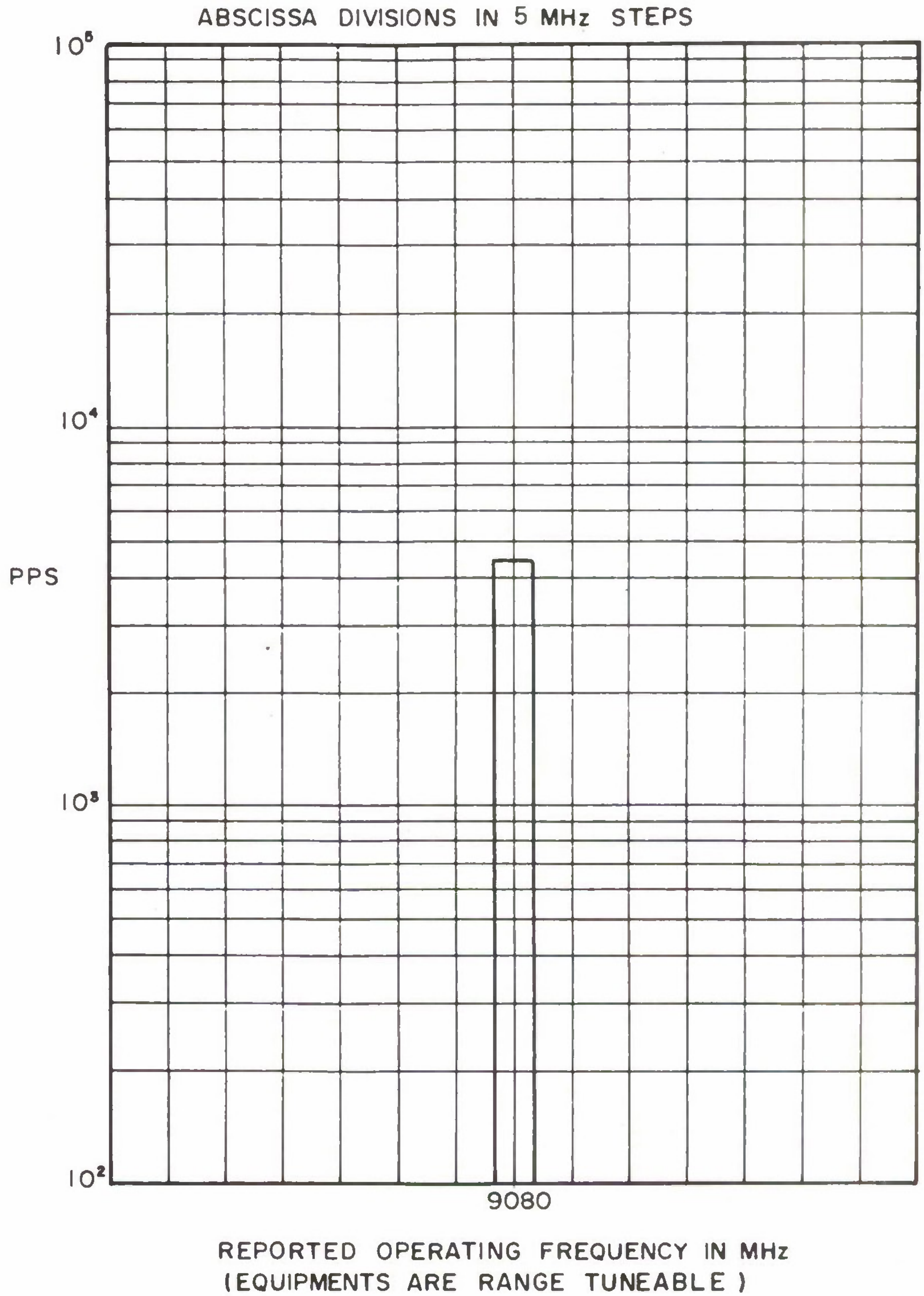

Figure I-24. Histogram of Cumulative Pulse Rate of Environmental Transmitters at New Orleans, Category B, 0.5 – 0.8 μs pulses

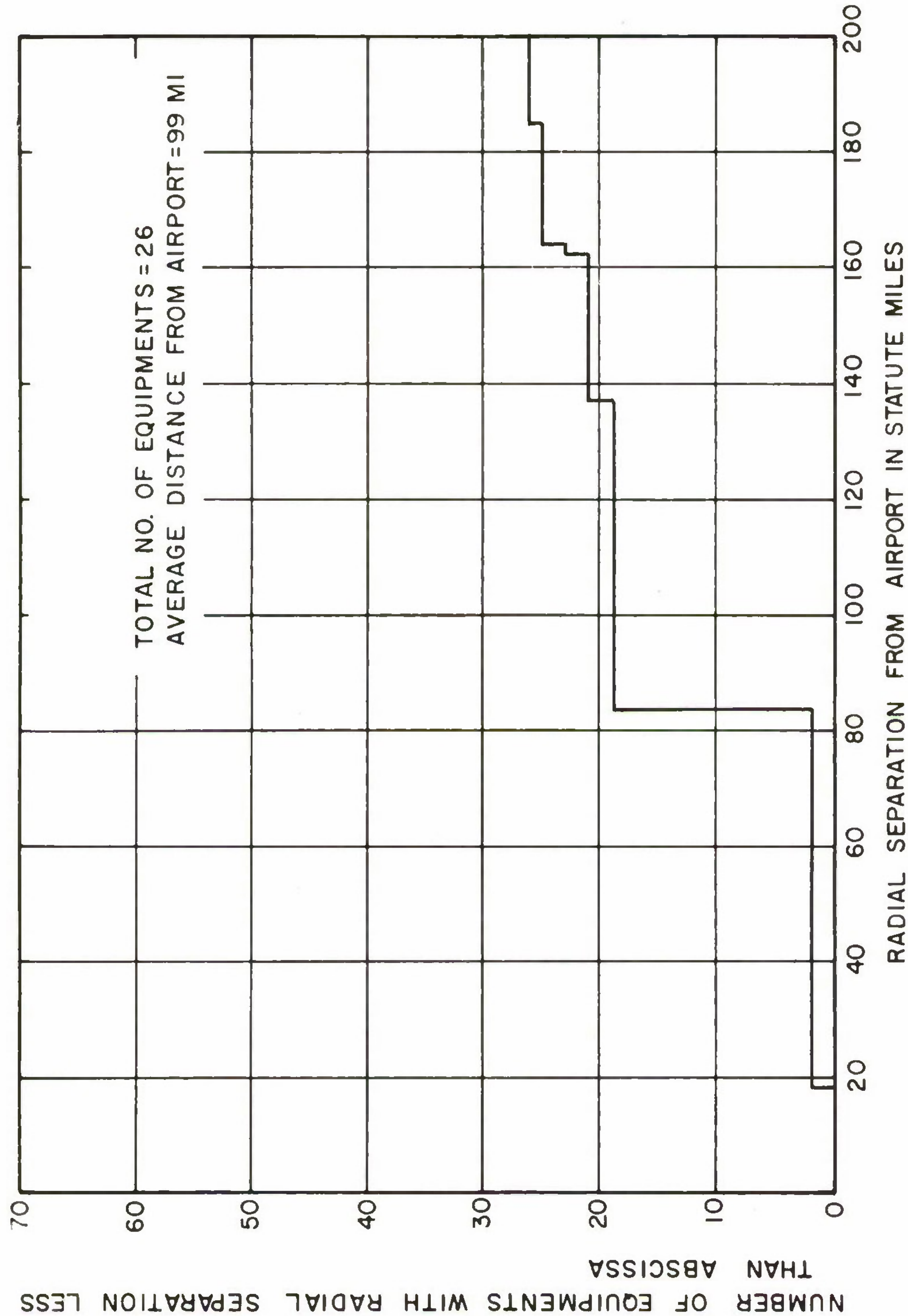

Figure I-25. Distribution of Emitters Within 200 Miles of New Orleans International Airport

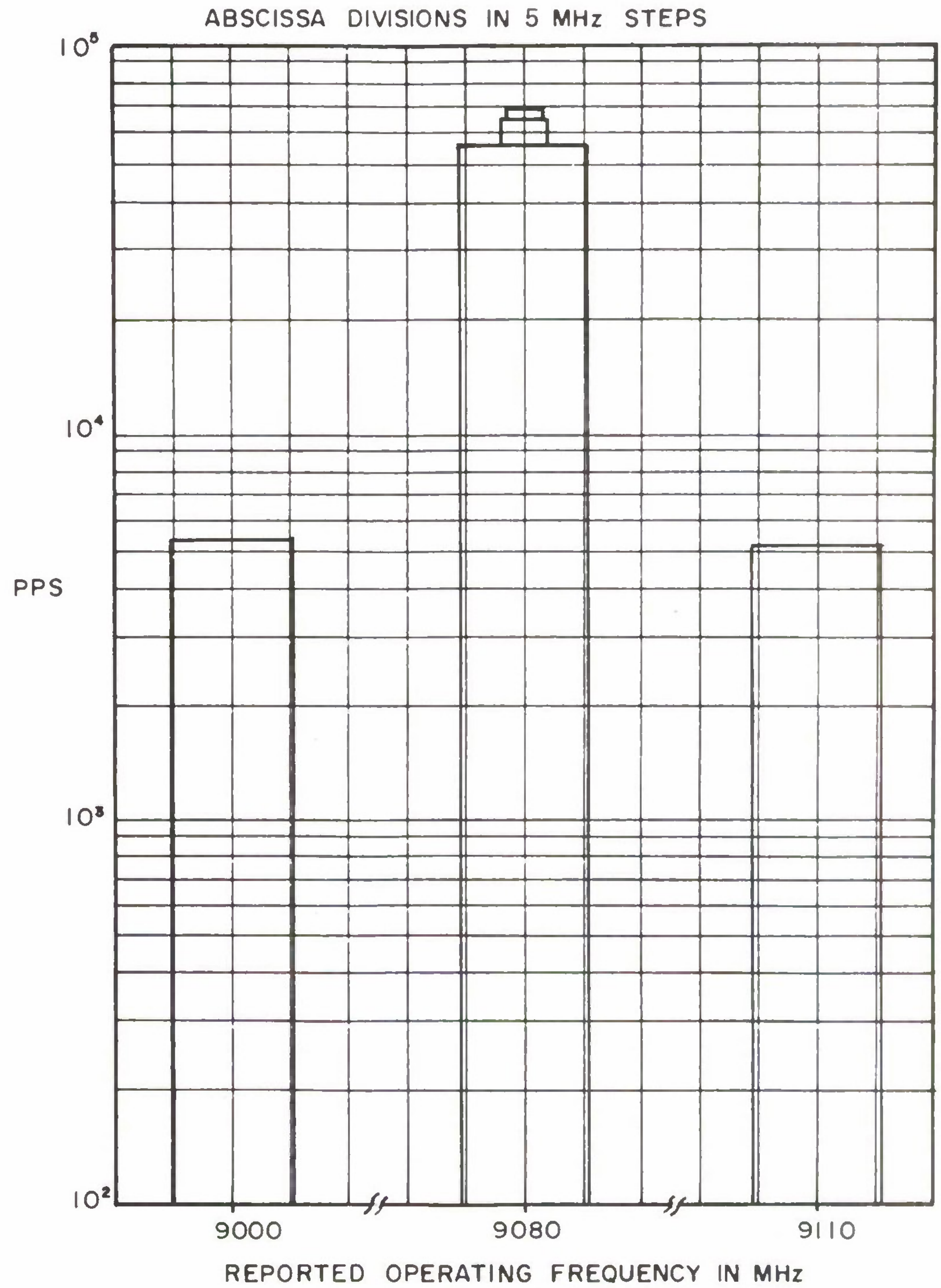

Figure I-26. Histogram of Cumulative Pulse Rate of Environmental Transmitters at Panama City, Category A, 0.12 – 0.2 μs pulses

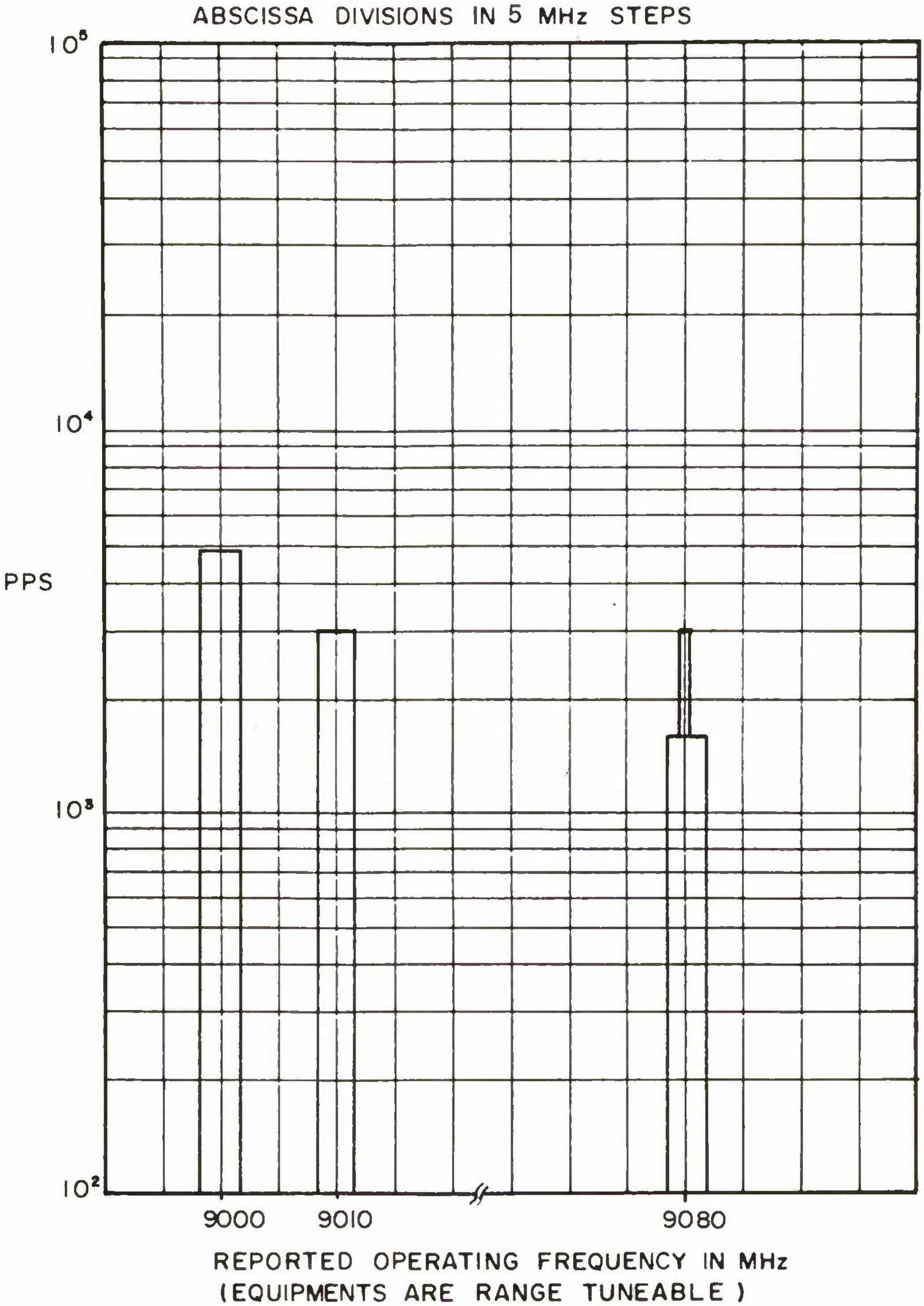

Figure I-27. Histogram of Cumulative Pulse Rate of Environmental Transmitters at Panama City, Category B, 0.5 – 0.8 μs pulses

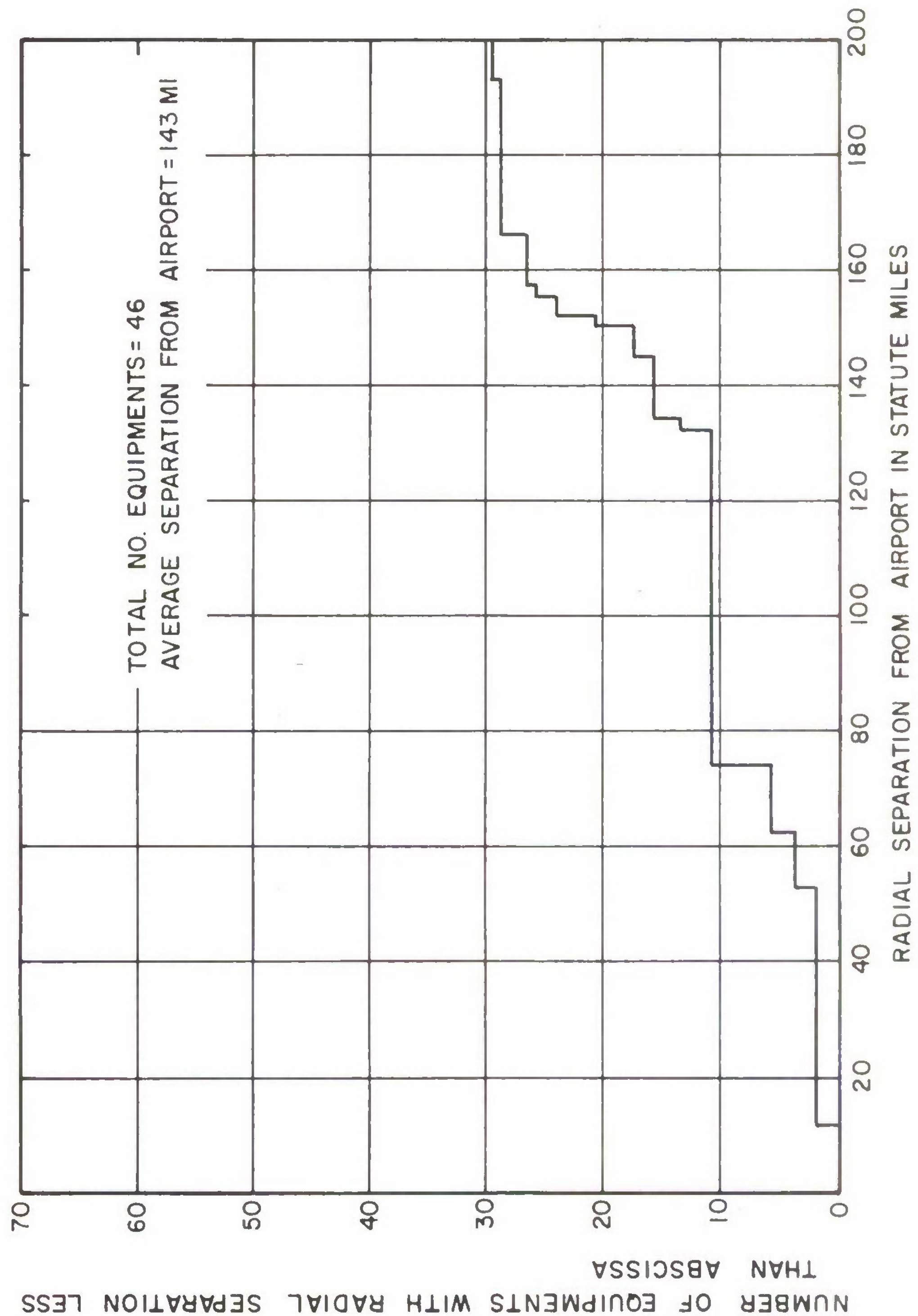

Figure I-28. Distribution of Emitters within 200 Miles of Panama City, Bay Co. Airport

TABLE I-1
EMITTERS NOT REPORTING FIXED FREQUENCY
ATLANTA, GEORGIA ENVIRONMENT

Category	Frequency Range of the Emitter (MHz)	PRF (pps)	Transmitter Bandwidth (MHz)
A	None		
B	9000 to 9160	1500	3.333
	9000 to 9160	1500	3.636
	9000 to 9160	1500	3.636
C	None		

TABLE I-2
EMITTERS NOT REPORTING FIXED FREQUENCY
BOSTON, MASSACHUSETTS ENVIRONMENT

Category	Frequency Range of the Emitter (MHz)	PRF (pps)	Transmitter Bandwidth (MHz)
A	9080 to 9110	5500	11
	9080 to 9110	5500	11
B	None		
C	None		

TABLE I-3
EMITTERS NOT REPORTING FIXED FREQUENCY
CHICAGO, ILLINOIS ENVIRONMENT

Category	Frequency Range of the Emitter (MHz)	PRF (pps)	Transmitter Bandwidth (MHz)
A	None	-----	-----
B	None	-----	-----
C	None	-----	-----

TABLE I-4
EMITTERS NOT REPORTING FIXED FREQUENCY
DALLAS, TEXAS ENVIRONMENT

Category	Frequency Range of the Emitter (MHz)	PRF (pps)	Transmitter Bandwidth (MHz)
A	None	-----	-----
B	9000 to 9160	1500	3.333
	9000 to 9160	1500	3.333
	9000 to 9160	1870	2.4
	9000 to 9170	1870	2.4
	9000 to 9160	1500	3.636
	9000 to 9160	1500	3.636
C	None	-----	-----

TABLE I-5
EMITTERS NOT REPORTING FIXED FREQUENCY
DULLES ENVIRONMENT

Category	Frequency Range of the Emitter (MHz)	PRF (pps)	Transmitter Bandwidth (MHz)
A	None	-----	-----
B	9080 to 9170	2000	2.4
	9080 to 9170	2000	2.4
	9000 to 9160	1500	3.636
	9000 to 9160	1500	3.636
	9000 to 9160	1500	3.636
	9000 to 9160	1500	3.333
	9000 to 9160	1500	3.333
	9000 to 9160	1500	3.333
C	9000 to 9180	2400	4.8
	9000 to 9180	2400	4.8
	9000 to 9160	2400	4.8
	9000 to 9160	2400	4.8

TABLE I-6
EMITTERS NOT REPORTING FIXED FREQUENCY
LOS ANGELES ENVIRONMENT

Category	Frequency Range of the Emitter (MHz)	PRF (pps)	Transmitter Bandwidth (MHz)
A	9080 to 9180	1833	11
	9000 to 9160	5500	11
	9000 to 9160	5500	11
	9000 to 9160	1500	4
	9000 to 9160	5500	11
	9000 to 9160	5500	11
	9000 to 9160	5500	11
	9000 to 9160	5500	11
B	9000 to 9180	2400	4
	9000 to 9180	2400	4
	9000 to 9180	1500	4
	9000 to 9160	1500	4
	9000 to 9160	1500	4
	9000 to 9160	1500	4
	9000 to 9180	2400	4
C	None	----	----

TABLE I-7
EMITTERS NOT REPORTING FIXED FREQUENCY
MIAMI ENVIRONMENT

Category	Frequency Range of the Emitter (MHz)	PRF (pps)	Transmitter Bandwidth (MHz)
A	None	-----	-----
B	None	-----	-----
C	None	-----	-----

TABLE I-8
EMITTERS NOT REPORTING FIXED FREQUENCY
NEW ORLEANS ENVIRONMENT

Category	Frequency Range of the Emitter (MHz)	PRF (pps)	Transmitter Bandwidth (MHz)
A	9000 to 9160	5500	11
	9000 to 9160	5500	11
	9000 to 9160	1833	11
	9000 to 9160	1833	11
	9000 to 9160	1833	11
	9000 to 9160	1833	11
	9000 to 9160	1833	11
	9000 to 9160	1833	11
	9000 to 9160	5500	11
	9000 to 9160	5500	11
	9000 to 9160	5500	11
	9000 to 9160	5500	11
	9000 to 9160	1833	11
	9000 to 9160	1833	11
	9000 to 9160	5500	11
	9000 to 9160	5500	11
B	None	----	-----
C	None	-----	-----

TABLE I-9
EMITTERS NOT REPORTING FIXED FREQUENCY
PANAMA ENVIRONMENT

Category	Frequency Range of the Emitter (MHz)	PRF (pps)	Transmitter Bandwidth (MHz)
A	9000 to 9160	5500	11
	9000 to 9160	5500	11
	9000 to 9160	1833	11
	9000 to 9160	1833	11
	9000 to 9160	1833	11
	9000 to 9160	1833	11
	9000 to 9160	1833	11
	9000 to 9160	1833	11
	9000 to 9160	5500	11
	9000 to 9160	5500	11
	9000 to 9160	5500	11
	9000 to 9160	5500	11
	9000 to 9160	1833	11
	9000 to 9160	1833	11
	9000 to 9160	5500	11
	9000 to 9160	5500	11
B	9000 to 9160	1500	3.333
	9000 to 9160	1500	3.636
	9000 to 9160	1500	3.636
C	None	-----	-----

APPENDIX II

ANALYTICAL PROCEDURE TO DETERMINE JFK AIRPORT ENVIRONMENT CONSTRAINTS ON ITG SYSTEM

The approach is outlined in Figure II-1. The details of the approach are as follows:

1. The analysis assumed that the ITGS runway-associated equipment was located on ILS runway No. 13 at JFK Airport. The equipment parameters were selected from Reference 2 as follows:

(a) <u>Ground DME Equipment</u>

Power = 200 watts, peak
Transmitter duty cycle = .028
Vertical beamwidth = 8°
Horizontal beamwidth = 40°
Azimuth = 312°, fixed
Pulse width = 1 microsecond
3 dB bandwidth = 1 MHz transmitter; 2 MHz receiver
Receiver sensitivity = −99 dBm (assumed)

(b) <u>Ground Angle Transmitters</u>

Power = 5 watts each
Modulation = C.W. only
3 dB bandwidth = 15 kHz
Antenna gains = 30 – 36 dB
Antenna coverage volume = 8° vertical, 40° horizontal

(c) <u>Aircraft DME Equipment</u>

Power = 100 watts peak
Transmitter PRF = 100 pps
Antenna gain = 7 dB
Pulsewidth = 1 microsecond
3 dB bandwidth = 1 MHz transmitter; 2 MHz receiver
Receiver sensitivity = −99 dBm (assumed)

*Block numbers correspond to sub-paragraph heading numbers.

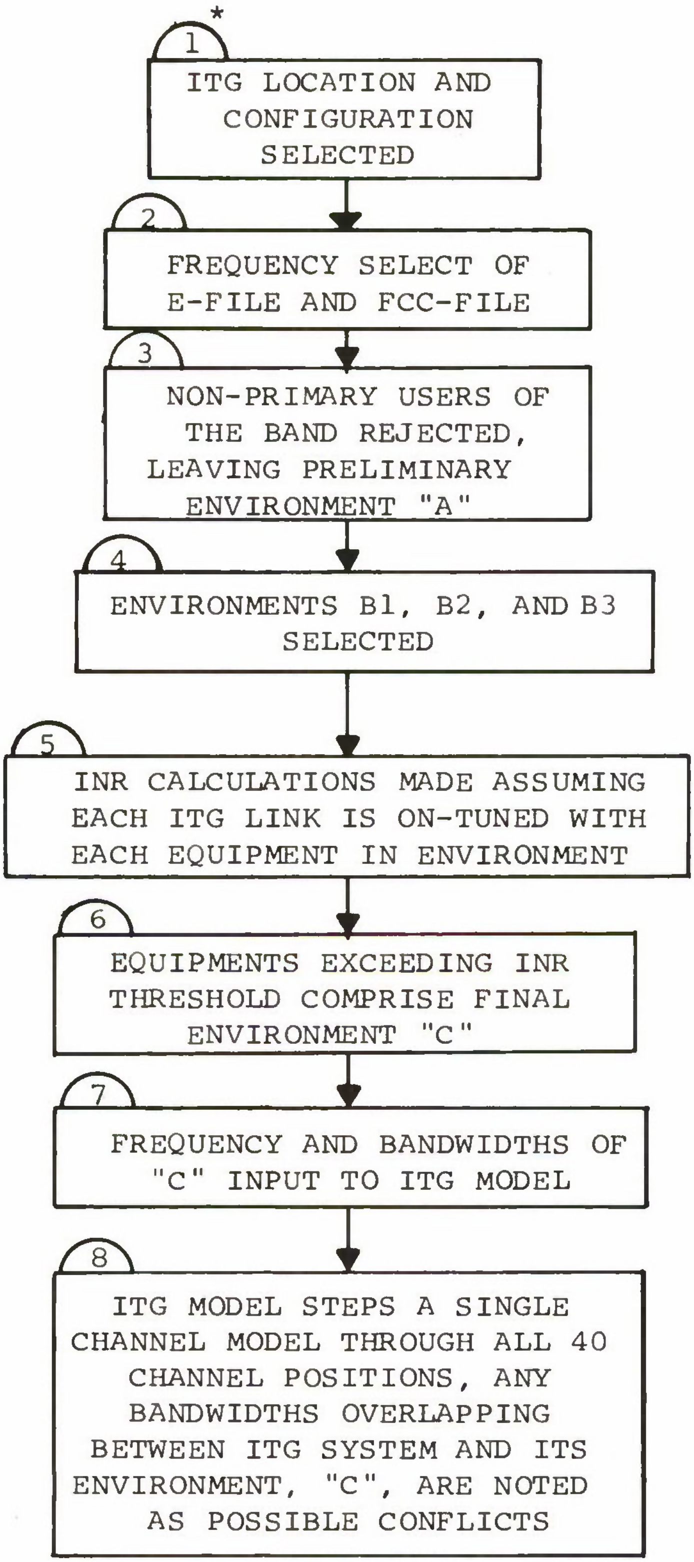

Figure II-1. Inter-System ITG Analysis Procedure

(d) Aircraft Angle Receivers

3 dB bandwidth = 15 kHz
Sensitivity = –99 dBm (assumed)
Antenna Gain = 7 dB

2. All present environment equipment allocations in the 8.975 to 9.225 GHz band were extracted from ECAC's Data Base. This is indicated in Block 2 of Figure II-1.

3. Non-primary users of the band, according to frequency allocation regulations, were removed from the list, leaving preliminary environment "A".

4. Three environments B1, B2, and B3 were derived from "A" in three steps. A computer program derived Environment B1 by selecting all transmitters/receivers within a radius of 25 miles of JFK Airport. The program derived environment B2 by selecting all transmitters/receivers outside of a 25-mile radius, but within 500 miles. The program derived environment B3 by selecting all transmitters/receivers within a 200-mile radius of JFK Airport.

5. These three environments were used in the following manner. Interference power to noise calculations were made with all four subchannels of an ITGS channel assumed to be in the on-tune condition with each equipment in environments B1, B2, and B3 as follows:

(a) For environment B1, aircraft ITGS equipment versus environment were assumed to have separation distances of 3,000 feet, gains assumed were for sidelobe antenna patterns; free space loss was assumed.

(b) For environment B2; aircraft ITGS equipment versus environment were assumed to have separation distances equal to the distance from the environmental equipment to the runway less 25 miles to simulate aircraft on circumference of a 25-mile circle. Smooth earth propagation path loss was assumed.

(c) For environment B3; runway (ground) equipment versus environment used rough earth propagation calculations.

6. All couplets computing a positive* interference to noise ratio were considered possible EMC conflicts and comprise environment "C". In fact, environment C is composed of eight subenvironments, each corresponding to one end of each of the 4 links of an ITGS channel. This coding is important to the process outlined in Block No. 8 of Figure II-1.

---

* This process was repeated with a +10 dB INR threshold.

7. The two most significant parameters of each environmental equipment at this point in the procedure (See Block 7 of Figure II-1) were its reported tuned frequency and its bandwidth occupancy. These two parameters were used to formulate a "picture" of the spectrum occupancy as seen from the ITGS centered at JFK Airport.

8. Each equipment representing a possible conflict in an "on-tune" condition was fixed as "occupying" a frequency slot equal to its bandwidth centered at its assigned frequency. The four frequency slots of an ITG channel were then placed in this environment. If any "conflict" (represented by a bandwidth overlap between an ITGS link and an equipment coded as incompatible in an on-tune condition) occurs, then the entire channel is considered "occupied".

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13. ABSTRACT

ABSTRACT

Results presented in this report issue from four tasks undertaken for the FAA. These results contribute to the specification of a concept for a guidance system for approach and landing. The electromagnetic emitter environment is established for the 1975 time frame for the frequency bands, 5.0 to 5.25 GHz, 9.0 to 9.2 GHz, and 15.4 to 15.7 GHz. Possible interactions between a proposed guidance system located at John F. Kennedy International Airport and the 9.0 to 9.2 GHz band emitter/receiver environment are established. Estimates are made of the minimum number of separate channels required of a guidance system. Channel frequency separation requirements for a specific signal format/system deployment are also established.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
C-BAND X-BAND Ku-BAND AIRBORNE NAVIGATION ENVIRONMENT TRANSPONDERS AIRCRAFT LANDINGS ELECTROMAGNETIC COMPATIBILITY						

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